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ADVANCED EXTRAVEHICULAR PROTECTIVE SYSTEMS STUDY

James G Sutton, Philip F Heimlich and Edward H Tepper

March 1972

PREPARED UNDER NASA CONTRACT NO. NAS 2-6021

for

National Aeronautics and Space Administration
Ames Research Center

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FOREWORD

These are the Subsystem Studies of the "Advanced Extravehicular Protective System (AEPS) Study". This effort was conducted by Hamilton Standard under contract NAS 2-6021 for the Ames Research Center of the National Aeronautics & Space Administration from July 1, 1970 to November 30, 1971. The AEPS Study was directed by Mr. James G. Sutton, and the principal investigators were Messrs. Philip F. Heimlich and Edward H. Tepper.

Special thanks are due to Dr. Alan B. Chambers, Environmental Control Research Branch, Biotechnology Division of the NASA Ames Research Center, Mr. William L. Smith, Chief of Crew Equipment Office for Manned Space Flight, Life Sciences Office of NASA Headquarters, and Mr. Thomas W. Herrala, Space Systems Department of Hamilton Standard for their advice and guidance.

This total report is contained in two volumes as listed below:

Volume I	Final Summary Report
Volume II	Subsystem Studies

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1.0 INTRODUCTION

1.0 INTRODUCTION

The United States manned space effort planned for the late 1970's and the 1980's consists of long duration missions with earth-to-orbit shuttles, orbiting space stations, possibly lunar bases, and eventually Mars landings. Extravehicular activity (EVA) is likely to take an increasingly important role in the completion of these future missions. However, with the potential of numerous EVA missions per man per week, the use of expendables in the portable life support system may become prohibitively expensive and burdensome. For future EVA missions to be effective in the total systems context, the portable life support system may need to have a regenerable capability.

The primary objective of the Advanced Extravehicular Protective System (AEPS) study is to provide a meaningful appraisal of various regenerable and partially regenerable portable life support system concepts for EVA use in the late 1970's and the 1980's.

The first phase of the AEPS Study was eleven months in duration and was devoted to an appraisal of portable life support system concepts for Space Station, Lunar Base and Mars EVA missions. The second phase was six months in duration and was devoted to an appraisal of portable life support system concepts for Shuttle EVA missions and emergency life support system concepts for Shuttle, Space Station, Lunar Base and Mars EVA missions.

This volume presents the results of the Subsystem Studies. Initial identification and evaluation of candidate subsystem concepts in the area of thermal control, humidity control, CO_2 control/O_2 supply, contaminant control and power supply are discussed in Section 2.0. The candidate concepts that were judged to be obviously non-competitive were deleted from further consideration and the remaining candidate concepts were carried into the go/no go evaluation. Conduction of the go/no go evaluation and the subsequent results are described in Section 3.0.

A detailed parametric analysis of each of the thermal/humidity control and CO_2 control/O_2 supply subsystem concepts which passed the go/no go evaluation was conducted. The results of these parametric analyses are presented graphically in Section 4.0. Based upon the results of the parametric analyses, primary and secondary evaluations of the remaining candidate concepts were conducted as described in Section 5.0. These results and the subsystem recommendations emanating from these results are discussed in Section 6.0. In addition, the parametric analyses of the recommended subsystem concepts were updated to reflect the final AEPS specification requirements and are also presented in Section 6.0. A detailed discussion regarding the selection of the AEPS operating pressure level is presented in section 7.0. A complete bibliography of the tests and references utilized in the conduction of the AEPS study is listed in Section 8.0

2.0 INITIAL CONCEPT IDENTIFICATION AND EVALUATION

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2.1 PHASE ONE EFFORT

The primary objective of phase one of the AEPS study was to provide a meaningful appraisal of various regenerable and partially regenerable portable life support concepts for EVA use on potential Space Station, Lunar Base and Mars landing missions in the 1980's.

To ensure that the results of this effort were both meaningful and useful for future related efforts, Hamilton Standard adopted a broad-based approach to candidate subsystem concept identification. The whole gamut of concept approaches were investigated with a specific effort on our part to preclude any prejudgment of concept value prior to concept identification.

To promote candidate concept identification, a thorough review of all available in-house data was conducted. In areas where in-house data were incomplete, an extensive literature survey was conducted and industry contacts were made, as required. Once all data was assembled and candidate subsystem concepts identified, a preliminary evaluation was held to screen out the candidates that were obviously noncompetitive. For purposes of the preliminary evaluation, all candidate concepts, unless specified otherwise, were sized for the most stringent EVA mission, the eight (8) hour lunar surface EVA mission, in accordance with the Lunar Base AEPS specification. All AEPS weight, AEPS power and vehicle impact estimates are presented in units of pounds. The vehicle impact estimates are based on a total of 180 EVA missions and must be multiplied by the number of crewmen going EVA per day to obtain a total vehicle impact. The assumed power, heat rejection and regeneration time penalties are defined in Table 2-1.

PENALTY	AEPS	VEHICLE
POWER	$100 \frac{\text{watt-hrs}}{\text{lb}}$	$0.7 \frac{\text{watts}}{\text{lb}}$
HEAT REJECTION	$1000 \frac{\text{BTU}}{\text{lb}}$	$0.04 \frac{\text{lbs}}{\text{BTU/hr}}$
REGENERATION TIME	---	12 hours

TABLE 2-1 ASSUMED PENALTIES

This section summarizes the initial candidate subsystem concepts identified and the results of the preliminary evaluation.

2.1.1 Thermal Control

The thermal control subsystem maintains thermal equilibrium of the suited crewman and provides AEPS equipment cooling, as required. The thermal loads imposed on the thermal control system consist of the crewman's metabolic load, other AEPS equipment loads and environmental heat leak. The thermal control area has been divided into the following six (6) basic categories to facilitate concept identification and preliminary evaluation:

2.1.1 (continued)

a. Expendable
b. Conduction
c. Convection
d. Radiation
e. Thermal Storage
f. Energy Conversion

In addition, a seventh category entitled "hybrid" is also included. Hybrid subsystem concepts are a combination of two or more concepts of any of the six basic categories.

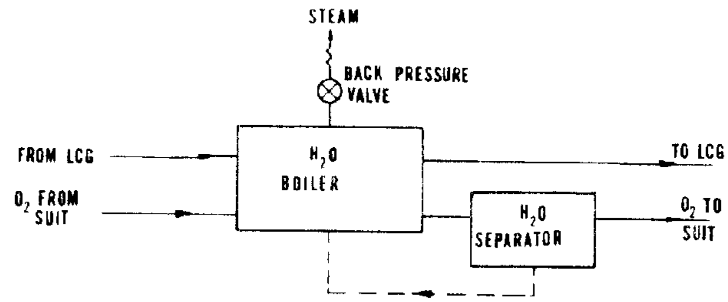
2.1.1.1 Expendable - Expendable thermal control concepts utilize the heat of sublimation or vaporization of the expendable and subsequent exhaust of the expendable into the ambient environment to reject heat and provide thermal control. A list of potential expendables for use in an AEPS configuration is as follows:

a. Water (H_2O)
b. Hydrogen Peroxide (H_2O_2)
c. Ammonia (NH_3)
d. Carbon Dioxide (CO_2)
e. Methane (CH_4)
f. Cryogenic Oxygen
g. Cryogenic Hydrogen
h. Feces/Urine Sludge

The expendable water thermal control concepts identified are:

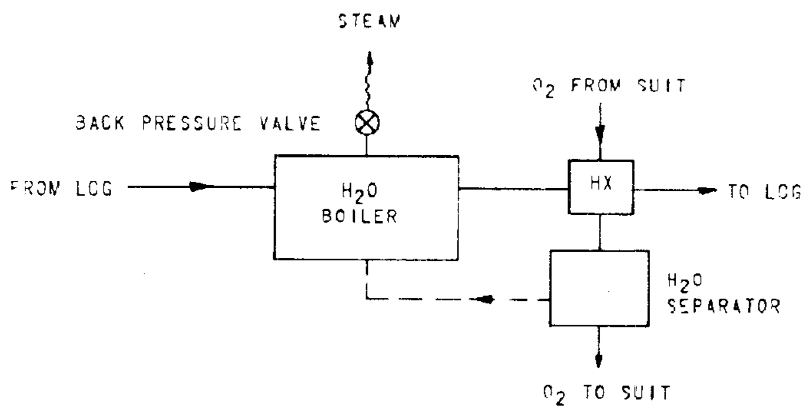
a. Water Boiler (Figure 2-1)
b. Super-Cooled Water Boiler (Figure 2-2)
c. Super-Cooled Water Boiler with Vapor Regenerative Cooling (Figure 2-3)
d. Water Sublimator (Figure 2-4)
e. Super-Cooled Water Sublimator (Figure 2-5)
f. Super-Cooled Water Sublimator with Vapor Regenerative Cooling (Figure 2-6)
g. Plate Fin Flash Evaporator
h. Nonsteady State Pulse Feed Flash Evaporator
i. Static Vortex Flash Evaporator
j. Turbine-Rotary Vortex Flash Evaporator (Figure 2-7)
k. Motor-Rotary Vortex Flash Evaporator (Figure 2-8)
l. Multi-Stage Flash Evaporator (Figure 2-9)
m. Vapor Diffusion Through Suit Pressure Valves (Figure 2-10)
n. Vapor Diffusion Through Water Permeable Membrane (Figure 2-11)

The expendable water thermal control concepts (with the exception of vapor diffusion through water permeable membrane which requires an extremely large membrane surface area) appear to be the only competitive expendable subsystems. They are



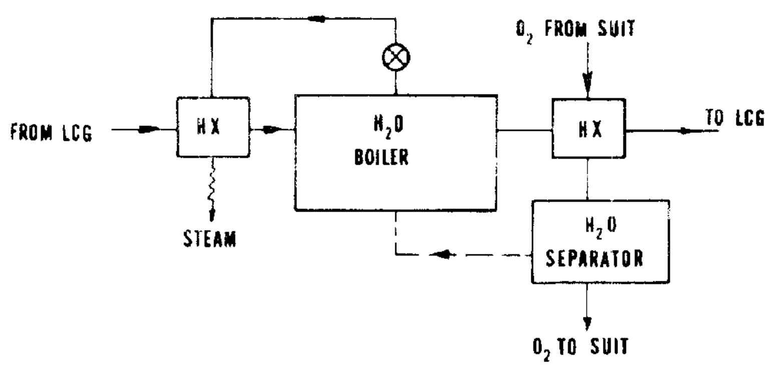
AEPS WT	AEPS POWER	VEHICLE IMPACT
24	0	2700+

FIGURE 2-1. WATER BOILER



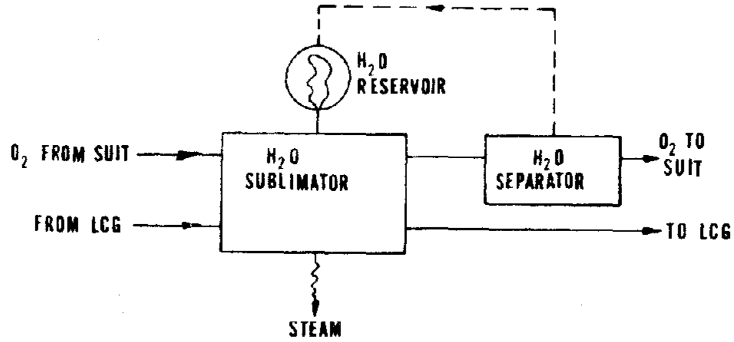
AEPS WT	AEPS POWER	VEHICLE IMPACT
28	0	2210+

FIGURE 2-2. SUPER-COOLED WATER BOILER



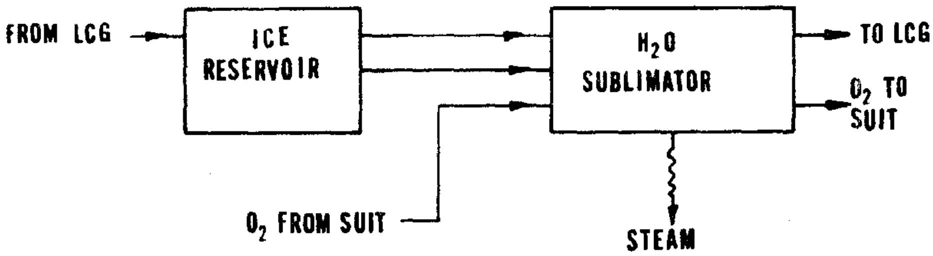
AEPS WT	AEPS POWER	VEHICLE IMPACT
29	0	2200+

FIGURE 2-3. SUPER-COOLED WATER BOILER WITH VAPOR REGENERATIVE COOLING



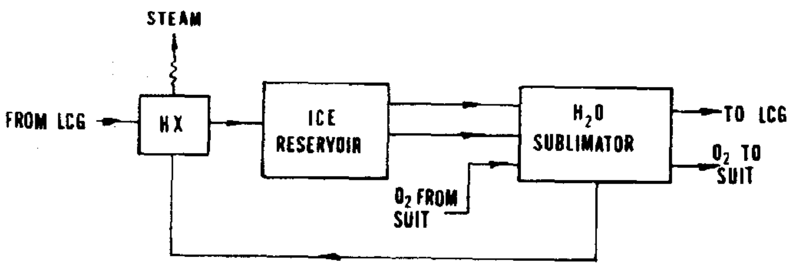
AEPS WT	AEPS POWER	VEHICLE IMPACT
28	0	2950

FIGURE 2-4. WATER SUBLIMATOR



AEPS WT	AEPS POWER	VEHICLE IMPACT
28	0	2450

FIGURE 2-5. SUPER-COOLED WATER SUBLIMATOR



AEPS WT	AEPS POWER	VEHICLE IMPACT
31	0	2410

FIGURE 2-6. SUPER-COOLED WATER SUBLIMATOR WITH VAPOR REGENERATIVE COOLING

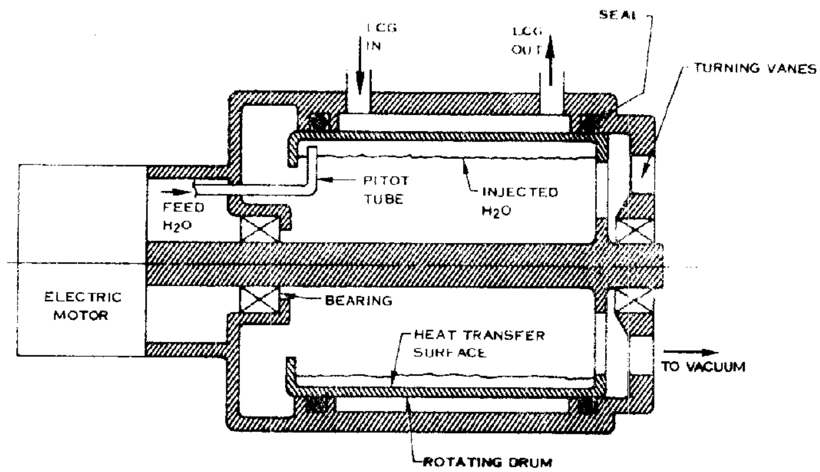


FIGURE 2-7. MOTOR-DRIVEN FLASH EVAPORATOR

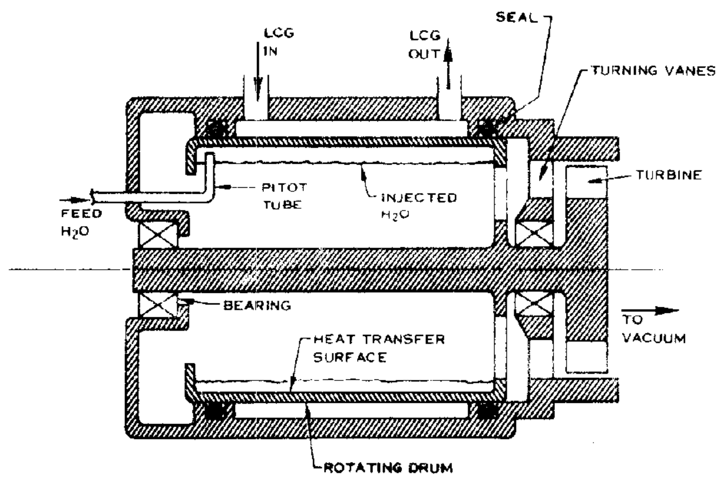
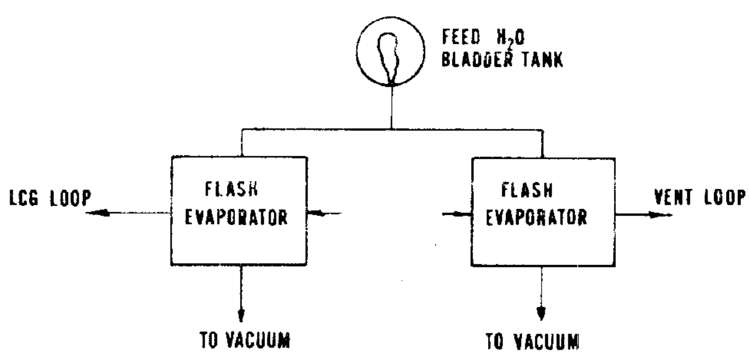
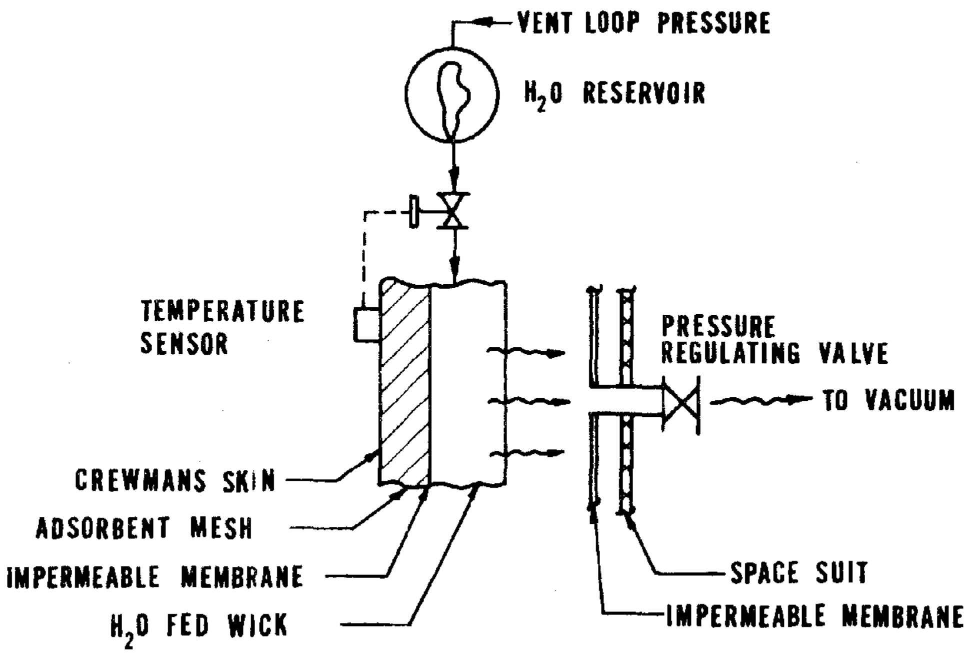


FIGURE 2-8. TURBINE-DRIVEN FLASH EVAPORATOR



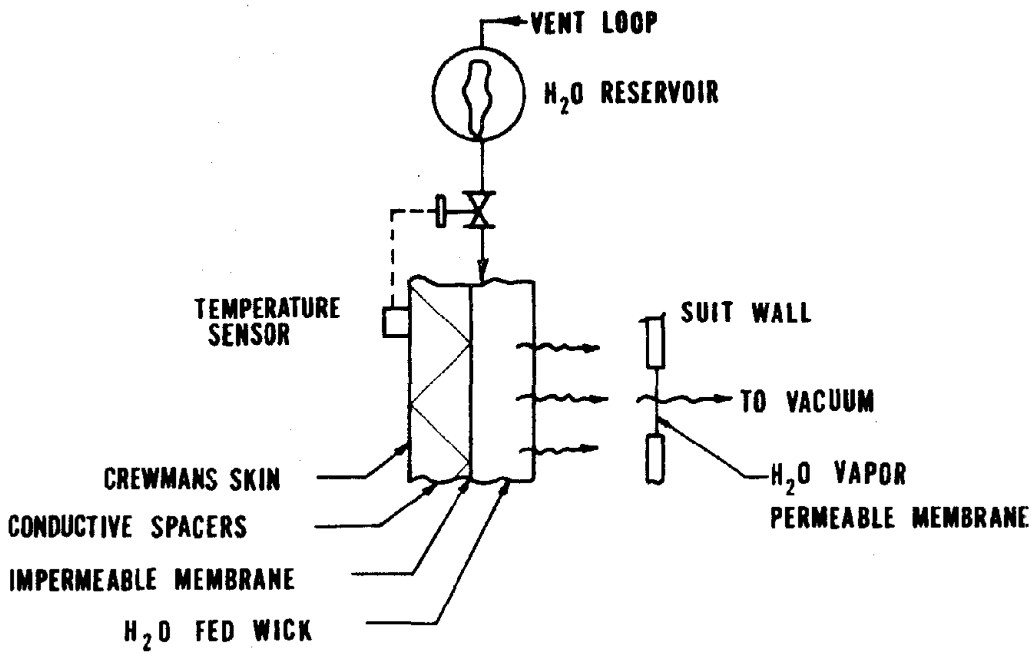
AEPS WT	AEPS POWER	VEHICLE IMPACT
28	0.3	2700+

FIGURE 2-9. MULTISTAGE FLASH EVAPORATOR



AEPS WT	AEPS POWER	VEHICLE IMPACT
25	0.6 CREDIT	3120

FIGURE 2-10- VAPOR DIFFUSION THROUGH SUIT PRESSURE VALVES



AEPS WT	AEPS POWER	VEHICLE IMPACT
600	0.6 CREDIT	111,000

FIGURE 2-11. VAPOR DIFFUSION THROUGH WATER PERMEABLE MEMBRANE

2.1.1.1 (continued)

lighter, smaller, represent a minimum relative vehicle impact, and present no appreciable handling or operational problems. In addition, water is an expendable which is normally stored and readily available in all three mission vehicles (Space Station, Lunar Base, Mars Excursion Module).

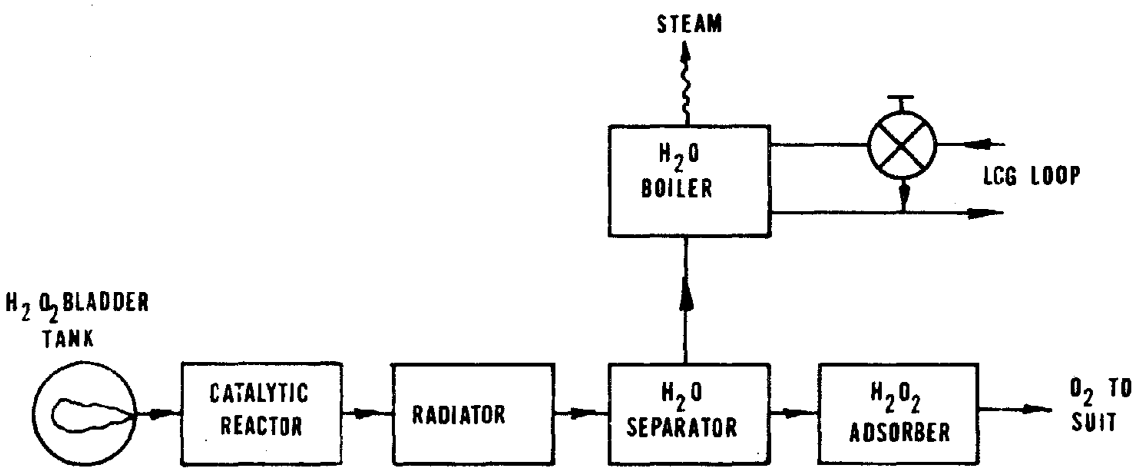
H_2O_2, as shown in figure 2-12, provides the dual function of O_2 supply and water supply and may be stored on the Space Station and/or the Mars Excursion Module (MEM) as a propellant. However, it represents three times the suit mounted weight and twice the vehicle impact of a comparable water system.

Table 2-2 presents a relative comparison of expendable water subsystems with NH_3, CO_2 and CH_4 subsystems. Nitrogen may be stored in any of our mission vehicles in the form of NH_3 and therefore, the NH_3 would be readily available as an expendable for an AEPS thermal control subsystem. However, it simply does not trade-off competitively relative to water.

Both CO_2 and CH_4 are waste products of a vehicle ECS and are normally vented overboard. The Space Station Prototype (SSP) ETC/LSS, which is being designed and developed by Hamilton Standard for the NASA Manned Spacecraft Center, nominally vents overboard 8.2 pounds of CO_2 and 6.6 pounds of CH_4 per day for a 12 man crew. Although these waste products could be used in an AEPS thermal control subsystem, they are not produced in sufficient quantity for use in frequent EVA excursions. In addition, there are handling and operational problems involved with storing and cooling these waste products for EVA use.

EXPENDABLE	AEPS WT	AEPS POWER	VEHICLE IMPACT
NH_3 Boiler	68	0	5050+
NH_3 Sublimator	65	0	4500+
CO_2 Boiler	237	0	24,300+ Less Vehicle Excess
CO_2 Sublimator	149	0	11,700+ Less Vehicle Excess
CH_4 Sublimator	97	0	17,500+ Less Vehicle Excess
H_2O Boiler	24	0	2700+
H_2O Sublimator	28	0	2950+

TABLE 2-2. EXPENDABLE CONCEPTS



AEPS WT	AEPS POWER	VEHICLE IMPACT
87	0	5060+

FIGURE 2-12. H_2O_2 (H_2O DUMP)

2.1.1.1 (Continued)

An AEPS configuration utilizing cryogenic oxygen (Figure 2-13) for thermal control is a relatively simple system which does not require active humidity control, CO_2 control, or trace contaminant control since it is an open system. However, it represents a large vehicle impact because cryogenic O_2 storage is not projected for mission vehicles of the 1980's. In addition, approximately seventy (70) pounds of expendable cryogenic O_2 are required for each EVA mission.

A cryogenic hydrogen thermal control subsystem (Figure 2-14) has the same basic drawback as cryogenic O_2; cryogenic H_2 storage is not projected for the mission vehicles of the 1980's.

The use of feces/urine sludge presents operational/handling/psychological problems that make this concept unattractive.

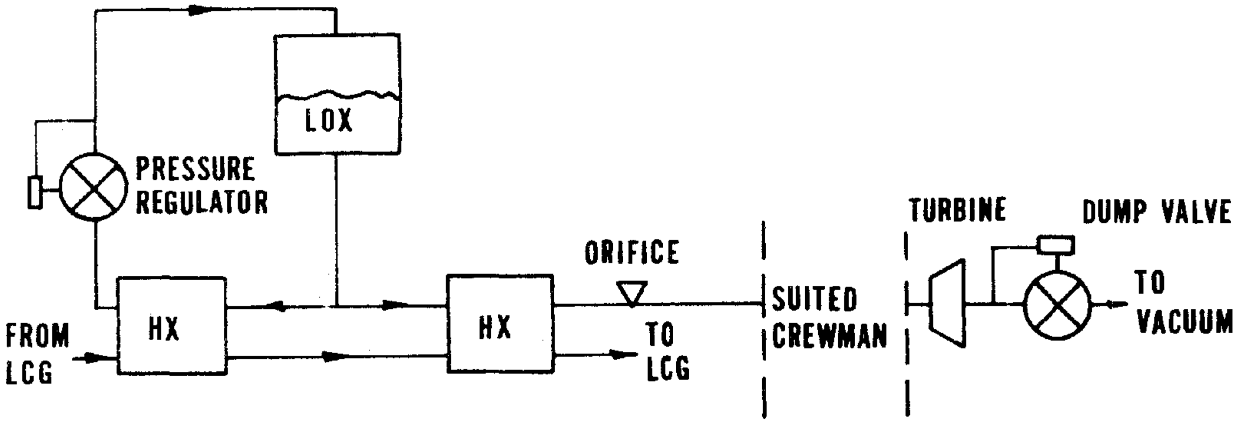
In summary, the expendable concepts selected for further evaluation only utilize water and are:

a. Boiler
b. Super-cooled Boiler
c. Sublimator
d. Super-cooled Sublimator
e. Plate Fin Flash Evaporator
f. Motor-Rotary Flash Evaporator
g. Vapor Diffusion through Suit Pressure Valves

The concepts utilizing vapor regenerative cooling were eliminated because they provided no advantage over the super-cooled concepts and, in fact, are heavier and more complex The two flash evaporator concepts selected were deemed the most competitive of the six considered.

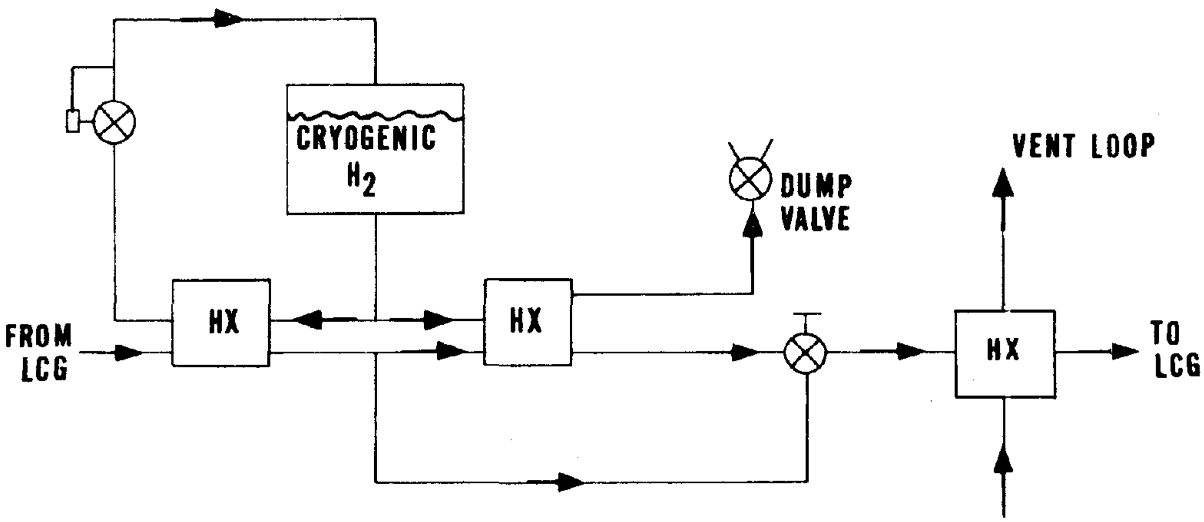
2.1.1.2 Conduction - Conduction was considered as a potential method of heat rejection for Lunar Base and Mars EVA missions. Conduction via the lunar soil is deemed impractical because of the large heat transfer area required (approximately 2000 square feet) due to the poor conductivity of the lunar soil. However, conduction via the Martian soil appears to be more promising because the presence of an atmosphere on Mars increases the conductivity of the Martian soil. An analysis utilizing environmental data gathered by Mariner 6 and 7 indicates that an AEPS configuration requires 5 square feet of heat transfer area on a Martian surface at a temperature of 20°F. Due to the preliminary nature of the Mariner data and the widely varying Martian surface conditions, this concept will be held in abeyance for future use.

2.1.1.3 Convection - Due to the presence of an atmosphere on Mars, free and forced convection were considered as potential methods of heat rejection for Mars EVA missions. Both free convection and forced convection (Figure 2-15) are noncompetitive due to the large heat exchanger size and enormous compressor power required. The Hilsch tube (Figure 2-16), which is an extension of the forced convection concept, was also found to be noncompetitive.



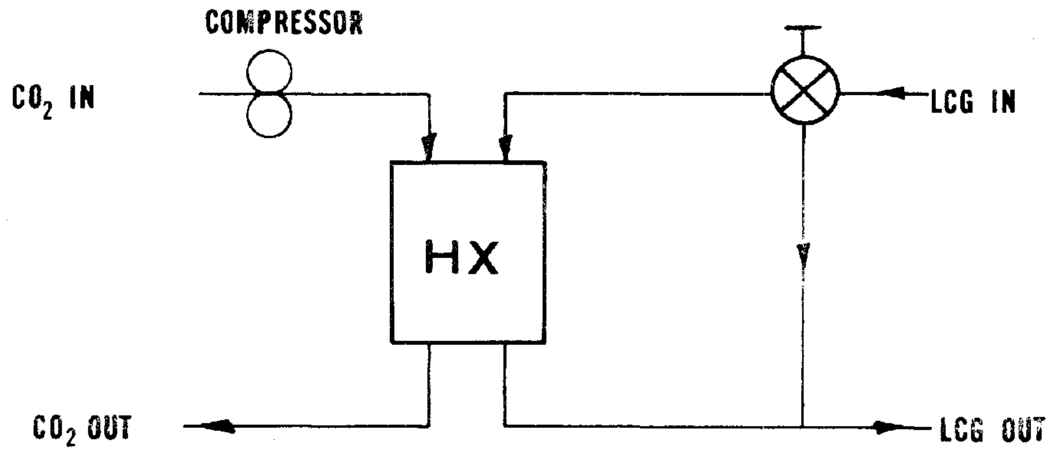
AEPS WT	AEPS POWER	VEHICLE IMPACT
136	3.2 CREDIT	12,900+

FIGURE 2-13. CRYOGENIC O_2 COOLING



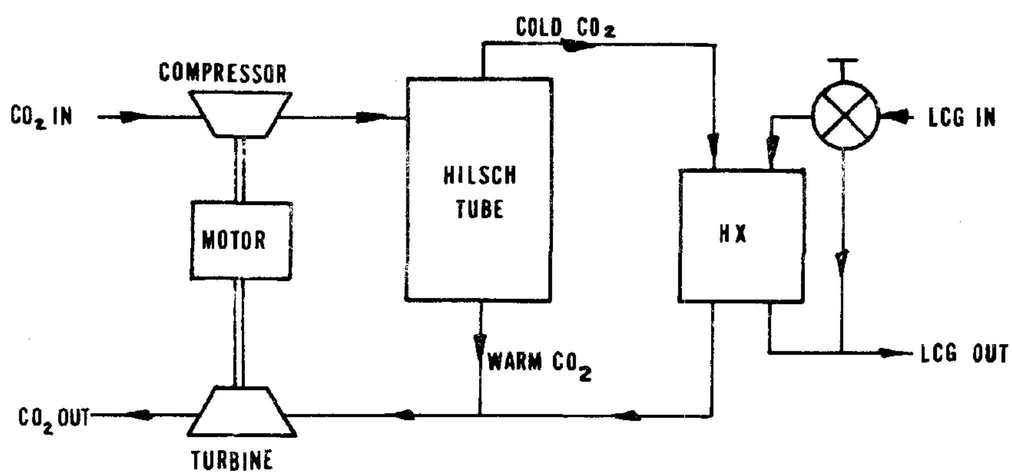
AEPS WT	AEPS POWER	VEHICLE IMPACT
28	—	1450 +

FIGURE 2-14. CRYOGENIC H_2



AEPS WT	AEPS POWER	VEHICLE IMPACT
160	20,000	283,000

FIGURE 2-15. FORCED CONVECTION – DIRECT COOLING



AEPS WT	AEPS POWER	VEHICLE IMPACT
$>$160	$>$20,000	$>$238,000

FIGURE 2-14. FORCED CONVECTION – OPEN LOOP HILSCH TUBE

2.1.1.4 Radiation - Radiation thermal control concepts are nonexpendable (except for power) concepts that have three inherent problem areas when applied to an EVA application: (1) large radiator area; (2) orientation; and (3) radiator surface degradation/contamination. A number of direct cooling and indirect cooling concepts were considered for the AEPS.

a. Direct cooling using either the LCG or heat pipes as the heat transport mechanism (Figures 2-17 and 2-18).
b. Direct cooling using water adsorption, as shown in Figure 2-19, and utilizing any of the water adsorbing chemicals listed in Table 2-3.
c. Indirect cooling using heat pump cycles such as:

    1) Vapor compression refrigeration cycle using freon (Figure 2-20)
    2) Water adsorption cycle using ammonia (Figure 2-21)
    3) Water adsorption cycle using lithium bromide (Figure 2-22)
    4) Brayton cycle using air (Figure 2-23)

Of these concepts identified, the following concepts were selected for further evaluation due to their lower relative AEPS weight and AEPS power impact:

a. Direct cooling using either the LCG or heat pipes
b. Direct cooling using water adsorption with either of the following compounds:

    1) $LiBr \cdot 3H_2O$
    2) $CaCl_2 \cdot 6H_2O$
    3) $Na_2Se \cdot 16H_2O$

c. Indirect cooling using a freon refrigeration cycle to minimize radiator area

2.1.1.5 Thermal Storage - Thermal storage concepts are regenerable concepts which utilize the latent heat of fusion and/or the sensible heat capacity of a material to reject heat. The following thermal storage concepts/compounds were identified and evaluated:

a. Subcooled ice (Figure 2-24) which has a heat of fusion of 144 Btu/lb at 32°F and an average heat capacity (Cp) of 0.37 Btu/lb-°F between -250° to + 32°F.
b. Transit 86, a thermal wax, which has a heat of fusion of 130 Btu/lb at 86°F (Figure 2-25).
c. Sodium sulphate ($Na_2SO_4 \cdot 10\ H_2O$), a eutectic salt, which has a heat of fusion of 92 Btu/lb at 88°F (Figure 2-25).
d. Phosphonium chloride (PH_4Cl) which has a heat of fusion of 324 Btu/lb at 82°F and above 48 atmospheres. (Figure 2-25)
e. Hydrogen which has an average heat capacity (C_V) of 2.15 between -250° to + 50°F (Figure 2-26).
f. Lunar or martian rock (Figure 2-27)

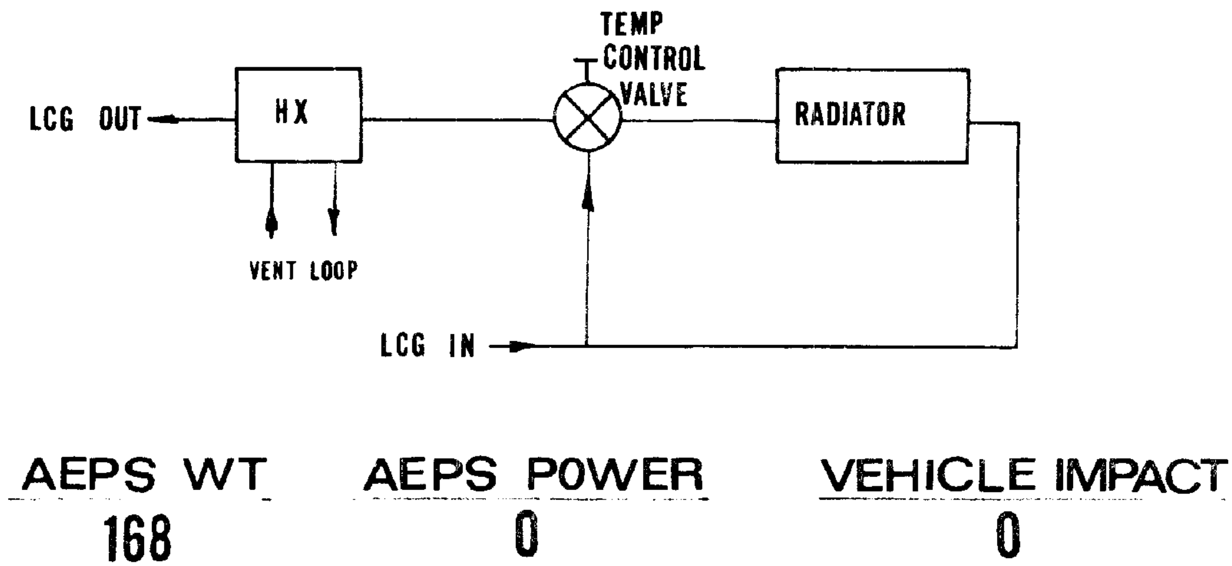


FIGURE 2-17. DIRECT COOLING USING LIQUID TRANSPORT LOOP

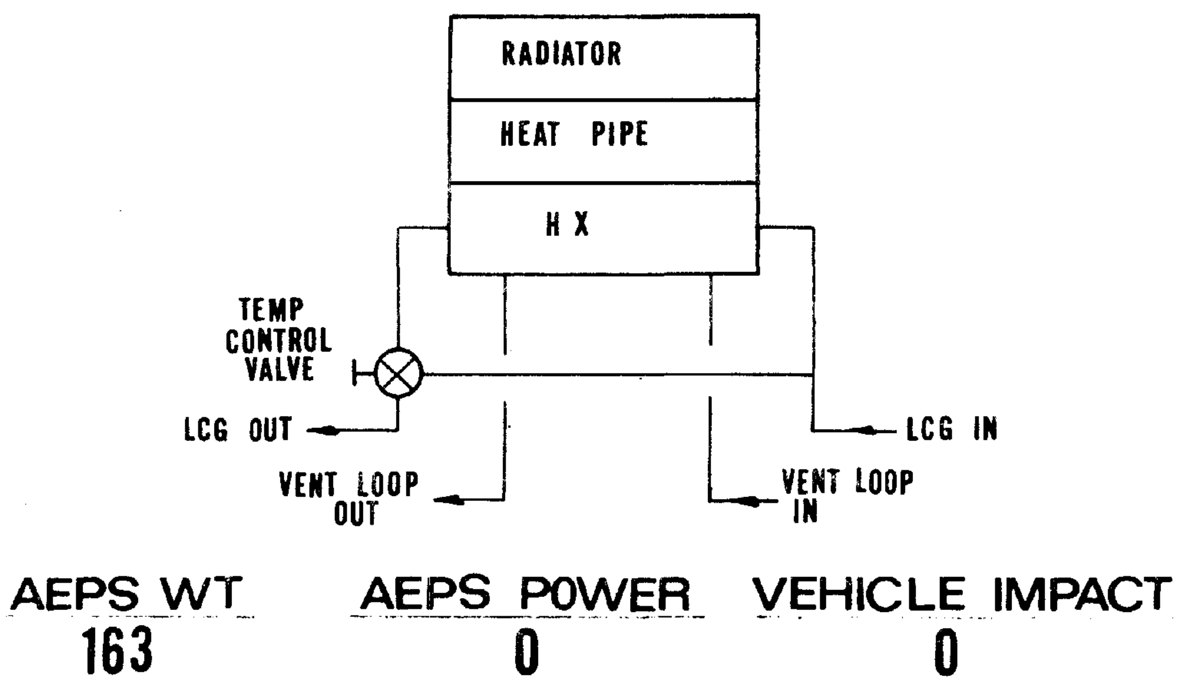


FIGURE 2-18. DIRECT COOLING USING HEAT PIPES

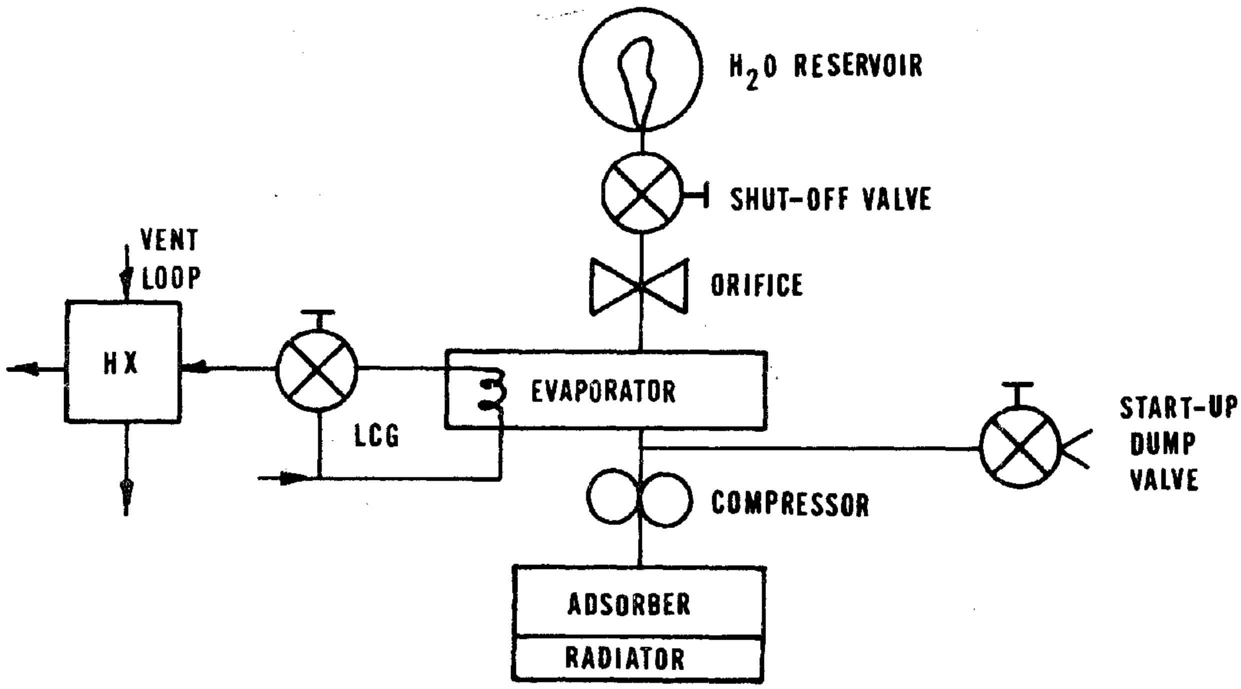
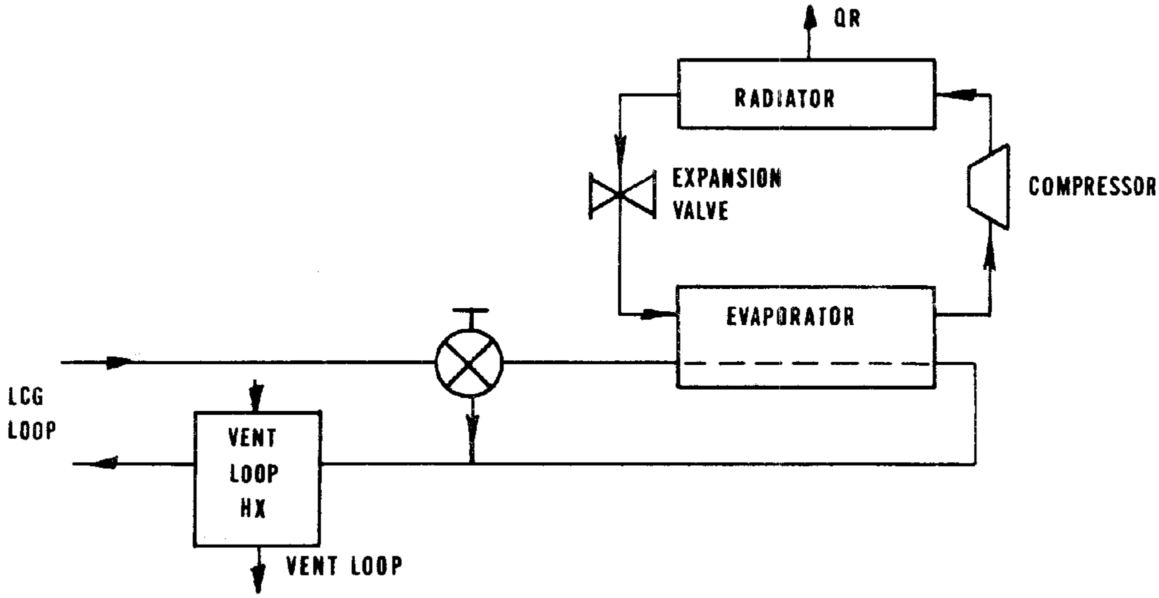


FIGURE 2–19. DIRECT COOLING USING WATER ADSORPTION

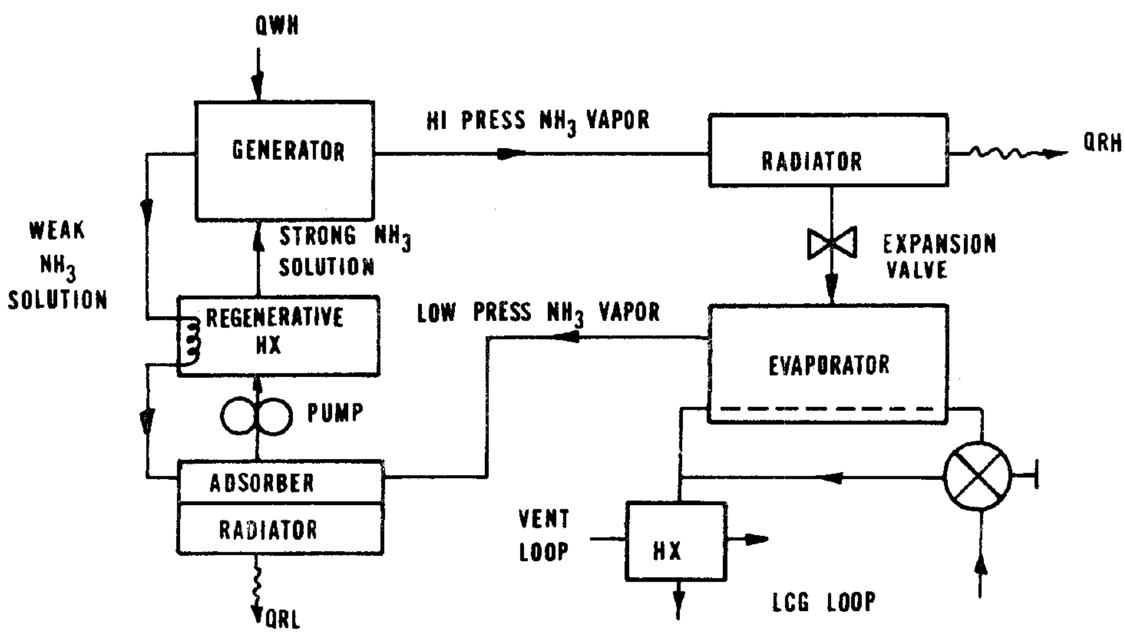
TABLE 2–3
DIRECT COOLING – H_2O ADSORPTION

CHEMICAL	CHEMICAL WT	AEPS WT	AEPS POWER	VEHICLE IMPACT
$LiCl\ 3H_2O$	23	149	24	1630 +
$CaCl\ \cdot 6H_2O$	16.5	103	24	810 +
MOL SIEVE	80	279	24	770 +
SILICA GEL	40	156	24	1670 +
$LiBr \cdot 3H_2O$	26	132	24	830 +
$Na_2Se \cdot 16H_2O$	7	75	24	750 +



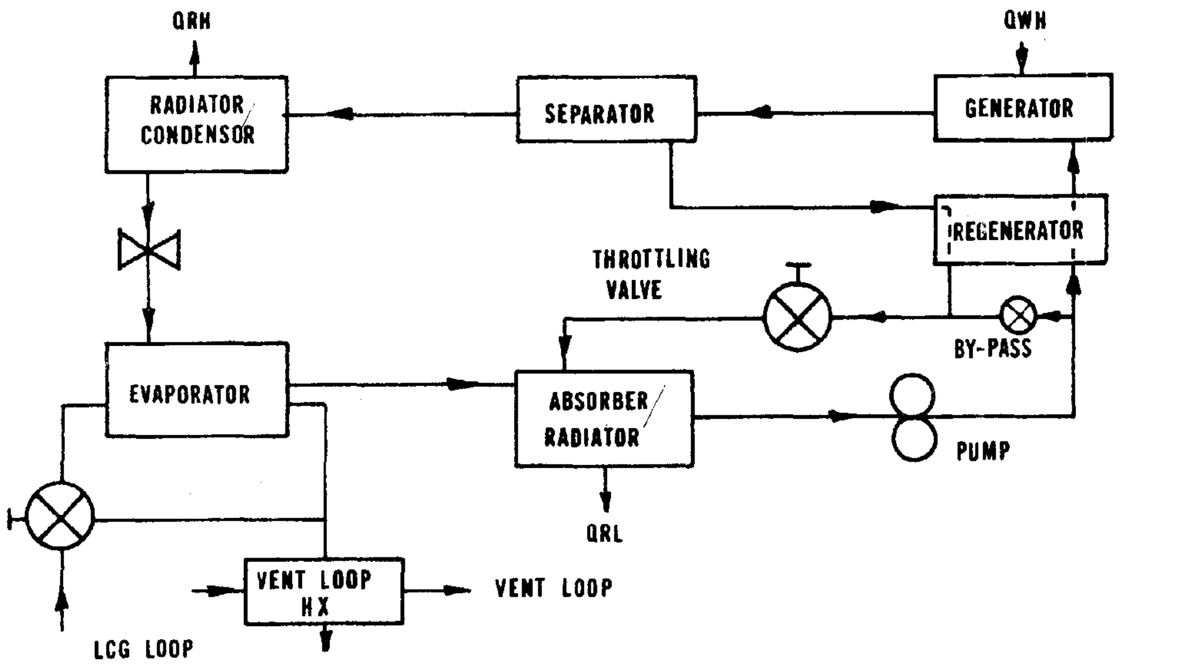
AEPS WT	AEPS POWER	VEHICLE IMPACT
122	12.5	150

FIGURE 2-20. INDIRECT COOLING USING FREON REFRIGERATION CYCLE



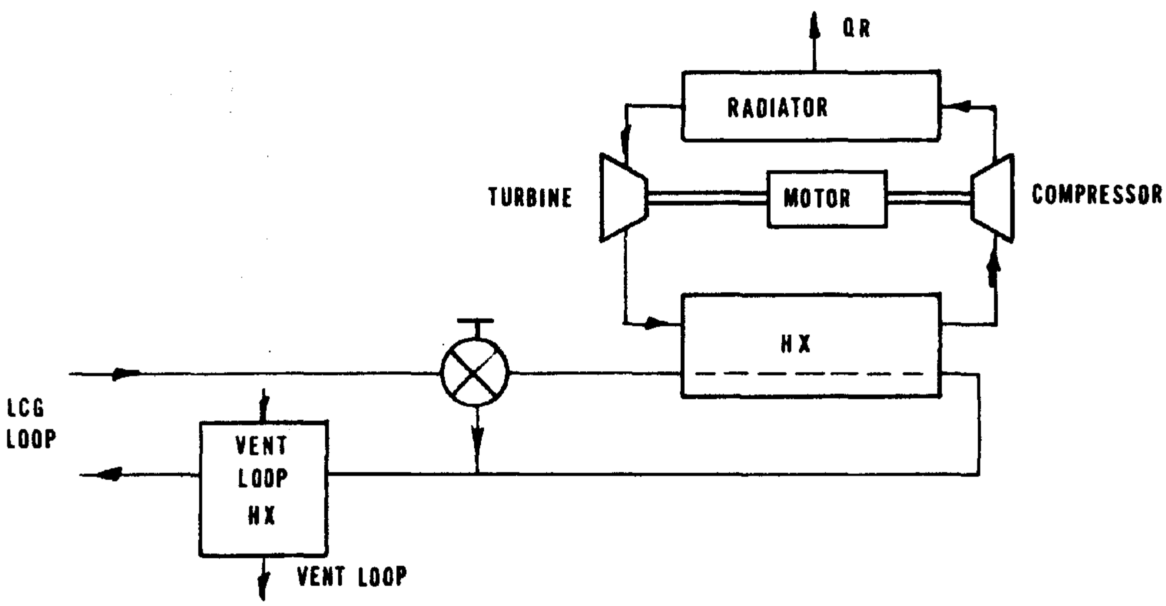
AEPS WT	AEPS POWER	VEHICLE IMPACT
127	89	1060

FIGURE 2-21. INDIRECT COOLING USING AMMONIA REFRIGERATION CYCLE



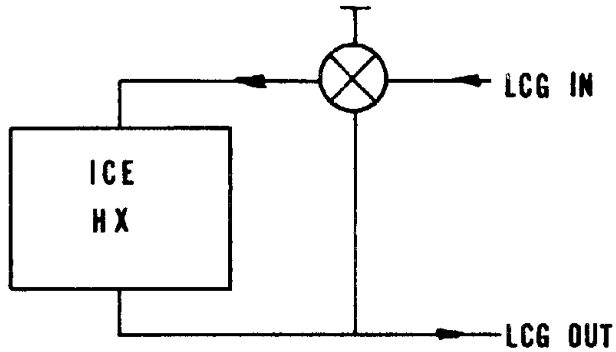
AEPS WT	AEPS POWER	VEHICLE IMPACT
93	136	1620

FIGURE 2–22. LiBr WATER ABSORPTION CYCLE



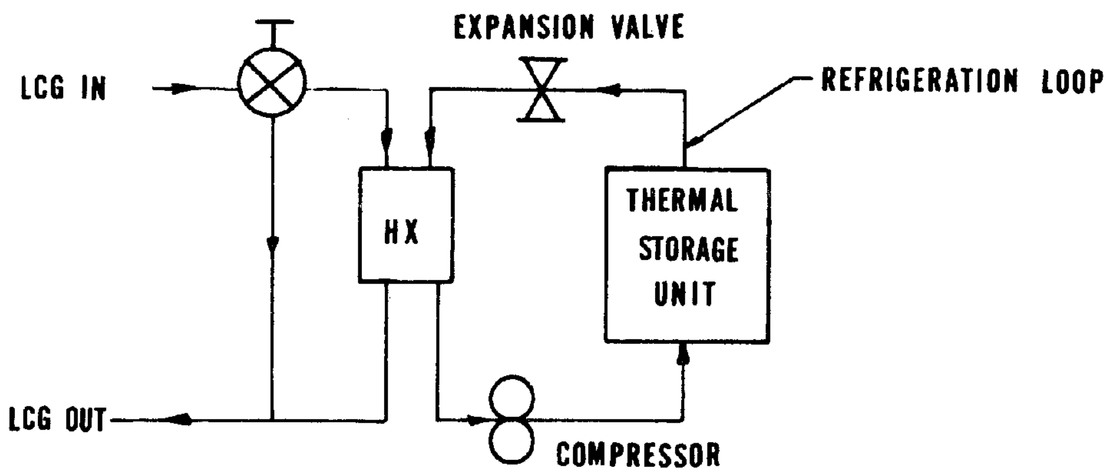
AEPS WT	AEPS POWER	VEHICLE IMPACT
508	98	1170

FIGURE 2–23. INDIRECT COOLING USING BRAYTON CYCLE



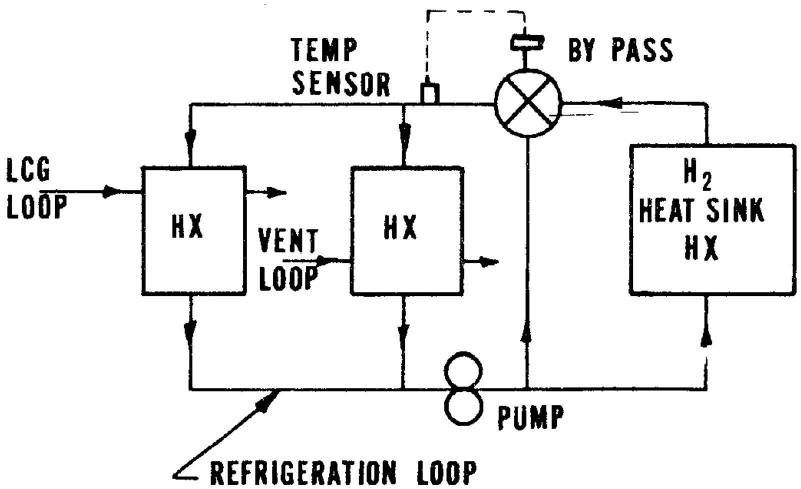
AEPS WT	AEPS POWER	VEHICLE IMPACT
126	0.3	550+

FIGURE 2-24. THERMAL STORAGE HEATING AND MELTING OF ICE



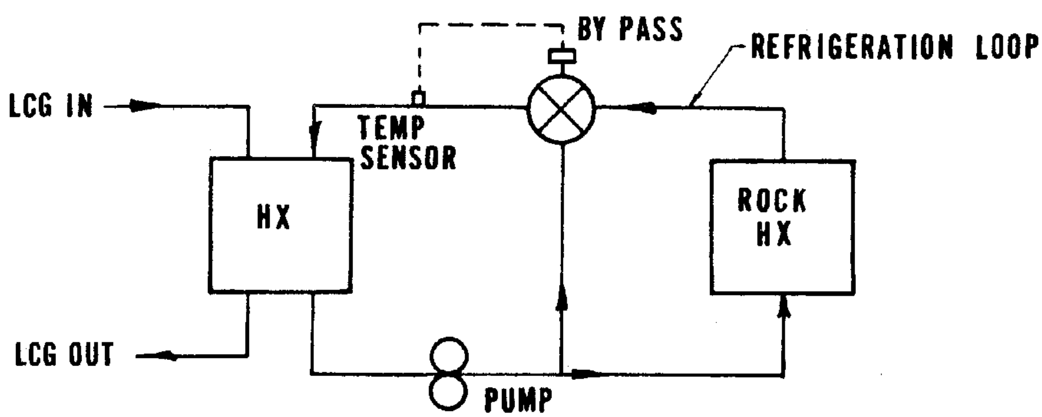
AEPS WT		AEPS POWER	VEHICLE IMPACT
WAX	329	24	286
EUTECTIC	457	25	300
PH_4Cl	144	20	240

FIGURE 2-25. THERMAL STORAGE, THERMAL WAX OR EUTECTIC SALT



AEPS WT	AEPS POWER	VEHICLE IMPACT
246	0.6	0

FIGURE 2–26. H_2 HEAT SINK



AEPS WT		AEPS POWER	VEHICLE IMPACT
LUNAR ROCK	>375	0	0
MARTIAN ROCK	>700	0	0

FIGURE 2–27. HEATING OF LUNAR OR MARTIAN ROCK

2.1.1.5 (Continued)

Of the six thermal storage concepts/compounds identified and evaluated, the following three have been selected for further evaluation due to their lower AEPS weight and AEPS power impact:

a. Subcooled ice
b. PH_4Cl
c. Hydrogen

2.1.1.6 Energy Conversion - Three modes of converting thermal energy into electrical energy were investigated: (1) thermoelectric, (2) thermionic; and (3) thermodielectric. All of these concepts require high source temperatures and large differential temperatures across the elements to attain efficiencies in the range of only 1 to 6%. Therefore, these concepts are not considered practical for the AEPS application.

2.1.1.7 Hybrid - Based upon the results of the preliminary evaluation of the thermal control concepts identified, the following hybrid thermal control concepts were selected for further evaluation:

a. Expendable/Radiation - Direct cooling
b. Expendable/Radiation - Heat Pump
c. Expendable/Thermal Storage - Ice
d. Expendable/Thermal Storage - PH_4Cl
e. Radiation/Thermal Storage Ice
f. Radiation/Thermal Storage - PH_4 Cl
g. Thermal Storage - PH_4 Cl/Water Adsorption

2.1.1.8 Summary - The thermal control subsystem concepts selected for further evaluation are:

a. H_2O Boiler
b. Super-cooled H_2O Boiler
c. H_2O Sublimator
d. Super-cooled H_2O Sublimator
e. Plate-fin Flash Evaporator
f. Rotary Flash Evaporator
g. Vapor Diffusion thru Suit Pressure Valves
h. Radiation - Direct Cooling
i. Vapor Compression Refrigeration Cycle using Freon
j. H_2O Adsorption - $CaCl_2$
k. H_2O Adsorption - LiBr
l. H_2O Adsorption Na_2Se
m. Thermal Storage Ice

2.1.1.8 (Continued)

n. Thermal Storage Subcooled Ice
o. Thermal Storage - PH_4 Cl
p. Thermal Storage - H_2
q. Expendable/Radiation - Direct Cooling
r. Expendable/Radiation - Heat Pump
s. Expendable/Thermal Storage - Ice
t. Expendable/Thermal Storage - PH_4Cl
u. Radiation/Thermal Storage - Ice
v. Radiation/Thermal Storage - PH_4 Cl
w. Thermal Storage - PH_4 Cl/H_2O Adsorption - $CaCl_2$
x. Thermal Storage - PH_4 Cl/H_2O Adsorption - LiBr
y. Thermal Storage - PH_4 Cl/H_2O Adsorption - Na_2Se

Humidity Control

The humidity control subsystem maintains the relative humidity within the space suit at a comfortable level for the suited crewman. Water vapor enters the gas stream as a product of crewman respiration and sweating and must be continually removed.

Selection of a humidity control subsystem is greatly dependent upon the thermal control subsystem (and in some cases, the CO_2 control subsystem) selected. Therefore, we have chosen only to identify the candidate humidity control subsystem concepts during this phase of the study and to postpone evaluation and selection of the candidate concepts until the system studies.

The candidate humidity control subsystem concepts identified are as follows:

a. Condensing heat exchanger combined with any of the following "change-of-momentum" type devices:

   1) Elbow wick separator
   2) Elbow scupper separator
   3) U-shaped gravity separator
   4) Vortex gravity separator
   5) Motor-driven rotory separator
   6) Turbine-driven rotary separator

b. Water vapor adsorption utilizing a dessicant such as silica gel
c. Water emulsion formation and storage
d. Freezeout

   1) Mechanical
   2) Cryogenic

2.1.2 (Continued)

e. Condensing heat exchanger in series with a hydrophobic/hydrophyllic screen separator
f. Water vapor diffusion through permeable membrane
g. Condensation and separation utilizing a Hilsch tube
h. Utilization of electrical energy to provide separation by -

    1) Electrolysis
    2) Electrophoresis
    3) Electroosmosis

i. Vapor dump

    1) Open loop vent system
    2) Semi-open loop vent system

2.1.3 CO2 Control

The CO2 control subsystem removes (and in some cases, concentrates) CO2 from the vent stream to maintain the CO2 partial pressure below a predetermined level to ensure safety of the suited crewman. The CO2 control area has been divided into four (4) basic categories to facilitate concept identification and preliminary evaluation:

a. Expendable
b. Regenerable
c. Electrochemical
d. Mechanical

2.1.3.1 Expendable - Numerous solid CO_2 sorbents were identified and classified into four groupings, as defined in Tables 2-4 through 2-7. The metal hydroxides are listed in Table 2-4, the metal superoxides in Table 2-5, the metal peroxides in Table 2-6, and the metal ozonides in Table 2-7. In addition to CO2 absorption, the superoxides, peroxides and ozonides also generate oxygen.

As can be seen, LiOH and Li_2O_2 have the highest theoretical CO_2 removal potential. Correspondingly, they also have exhibited the highest actual CO_2 removal efficiency in practice. Therefore, both these chemicals were selected to be carried forward for further evaluation as representative of the expendable solid CO_2 control concepts (Figure 2-28).

An expendable liquid sorbent subsystem (Figure 2-29) using a KOH solution was investigated and found to be heavier, bulkier, and more complex than the solid sorbent subsystems, and therefore, not as competitive.

TABLE 2-4
CARBON DIOXIDE ABSORPTION CAPABILITIES OF GROUP IA AND IIA METAL HYDROXIDES

Hydroxide	Formula Weight	Wt. % H_2O (3)	Lbs. CO_2/Lb. Hydroxide	Lbs. Hydroxide/ Lb. CO_2
LiOH	23.95	37.62	0.919	1.089
NaOH	40.00	22.53	0.550	1.818
KOH	56.11	16.06	0.392	2.550
$Mg(OH)_2$	58.34	30.89	0.754	1.326
$Ca(OH)_2$	74.10	24.32	0.594	1.684
$Sr(OH)_2$	121.65	14.81	0.362	2.765
$Ba(OH)_2$	171.38	10.52	0.257	3.896
Baralyme(93) (1)	87.50	29.75	0.503	1.988
Soda Lime(58-61) (2)	46.77	37.42	0.488	2.051

(1) Composition: 80 weight % $Ca(OH)_2$, 20 weight % $Ba(OH)_2 \cdot 8H_2O$ which corresponds to 0.945 moles $Ca(OH)_2$ and 0.055 moles $Ba(OH)_2 \cdot 8H_2O$.

(2) Composition: 4.5 weight % NaOH, 17.5 weight % H_2O, and 78 weight % $Ca(OH)_2$ which corresponds to 0.0582 moles NaOH, 0.4520 moles H_2O, and 0.4898 moles $Ca(OH)_2$.

(3) % H_2O based on $M^I_2O.H_2O$ or $M^{II}O.H_2O$

TABLE 2-5
CARBON DIOXIDE ABSORPTION CAPACITIES OF GROUP IA AND IIA METAL SUPEROXIDES

Superoxides	Formula Wt.	% Available O (2)	Lbs. CO_2/Lb. Superoxide	Lbs. Superoxide/ Lb. CO_2
LiO_2	38.94	61.63	0.565	1.770
NaO_2	54.99	43.64	0.400	2.499
KO_2	71.10	33.76	0.309	3.232
$Mg(O_2)_2$	88.32	54.35	0.498	2.007
$Ca(O_2)_2$	104.08	46.12	0.423	2.365
$Si(O_2)_2$	151.63	31.66	0.290	3.446
$Ba(O_2)_2$	201.36	23.84	0.219	4.575
Mixed Oxides (94) (1)	72.31	31.24	0.358	2.794

(1) Corresponds to a mixture of 0.3 moles Na_2O_2 to 1.4 moles KO_2. At this composition an R. Q. of 0.83 is theoretically achieved: 0.3 Na_2O_2 + 0.3 $CO_2 \longrightarrow$ 0.3 Na_2CO_3 + 0.15 O_2 and 1.4 KO_2 + 0.7 $CO_2 \longrightarrow$ 0.7 K_2CO_3 + 1.2 O_2.

(2) % available O based on (1/2 M^I_2O).1.50 or $M^{II}O$.1.50

TABLE 2-6
CARBON DIOXIDE ABSORPTION CAPACITIES OF GROUP IA AND IIA METAL PEROXIDES

Peroxide	Formula Wt.	% Available O (1)	Lbs. CO_2/Lb. Peroxide	Lbs. Peroxide/ Lb. CO_2
Li_2O_2	45.88	34.87	0.959	1.043
Na_2O_2	77.98	20.52	0.564	1.772
K_2O_2	110.20	14.52	0.399	2.504
MgO_2	51.32	28.41	0.781	1.280
CaO_2	72.08	22.20	0.610	1.638
SiO_2	119.63	13.38	0.368	2.719
BaO_2	169.36	9.45	0.260	3.849

(1) % available O based on $M^{I}_{2}O \cdot O$ or $M^{II}O \cdot O$

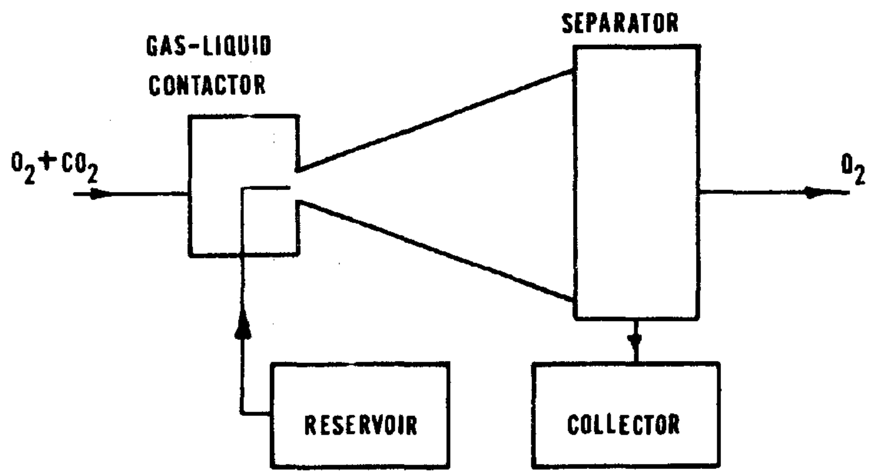
TABLE 2-7
CARBON DIOXIDE ABSORPTION CAPACITY OF GROUP IA METAL OZONIDES

Ozonide	Formula Wt.	% Available O (1)	Lbs. CO_2/Lbs. Ozonide	Lbs. Ozonide/ Lb. CO_2
LiO_3	54.94	72.81	0.400	2.498
NaO_3	70.99	56.35	0.310	3.227
KO_3	87.10	45.92	0.253	3.959

(1) % available O based on $(1/2\ M^{I}_{2}O) \cdot 2.5O \longrightarrow 1/2\ M^{I}_{2}O + 2.5\ O$.

SORBENT	AEPS WT	AEPS POWER	VEHICLE IMPACT
LiOH	10.4	.24	1030+
Li_2O_2	8.2	.24	1220+

FIGURE 2-28. SOLID SORBENT



AEPS WT	AEPS POWER	VEHICLE IMPACT
22	0.2	2040+

FIGURE 2-29. LIQUID SORBENT

2.1.3.1 (Continued)

A third type of expendable CO_2 control subsystem evaluated was the purge flow concept (Figure 2-30). This concept appears to be competitive only for infrequent short duration EVA missions, and will not be considered further unless changes in AEPS specification requirements make this a more desirable concept.

2.1.3.2 Regenerable - Numerous regenerable solid sorbent subsystem concepts were identified and evaluated including both cyclic (AEPS regenerable) and noncyclic (vehicle regenerable) concepts. Activated charcoal and molecular sieve (Figures 2-31 and 2-32) are physical adsorptive-type reactions while metallic oxides and solid amines are chemisorption-type reactions.

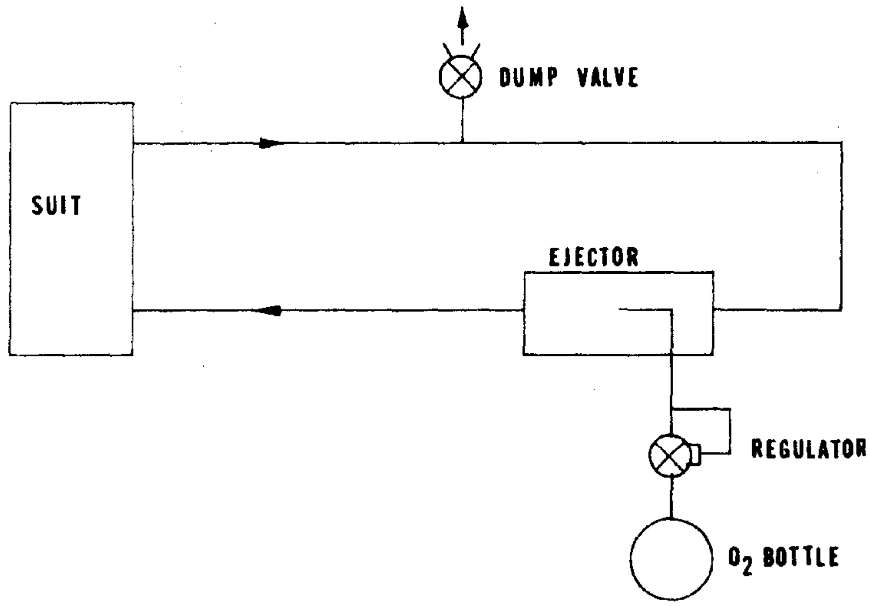
The metallic oxides identified and evaluate are defined in Table 2-8. Table 2-9 defines the free energy change for the regeneration of various metallic oxides which have reacted with CO_2 to form a carbonate. The carbonates with the low positive free energy values are the least stable and should be the easiest to regenerate.

The solid amine identified and evaluated is a proprietary compound presently being developed by Hamilton Standard.

A summary of AEPS and vehicle impact for both the cyclic and noncyclic solid regenerable sorbent subsystem candidate concepts are shown in Tables 2-10 and 2-11, respectively. The cyclic concepts which appear to be competitive are molecular sieve, metallic oxides and solid amine while the noncyclic concepts which are competitive are the metallic oxides. Although the noncyclic solid amine concept could be a viable competitor if CO_2 removal capacity can be dramatically increased, it has been excluded from further evaluation for this study.

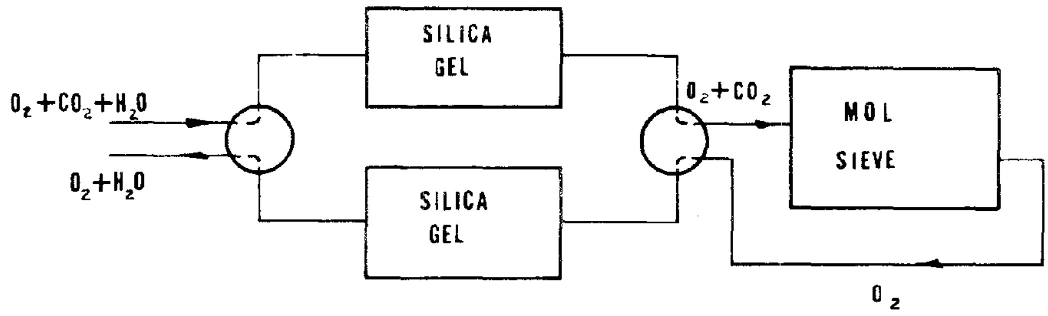
Two regenerable liquid sorbents, aqueous carbonate solution (K_2CO_3) and a liquid amine solution (PEI), were identified and evaluated. A number of cyclic and noncyclic schematic configurations were evaluated including the two cyclic configurations shown in Figures 2-33 and 2-34. As shown in Table 2-12, only the cyclic concepts are competitive with the regenerable solid sorbents.

2.1.3.3 Electrochemical - Four electrochemical concepts were identified and evaluated for potential use in an AEPS configuration. A hydrogen depolarized cell is shown in Figure 2-35 and two-stage and one-stage carbonation cell concepts are shown in Figures 2-36 and 2-37, respectively. Electrodialysis (Figure 2-38) and fused salt (Figure 2-39) concepts, in addition to providing CO_2 control, also provide a portion of the oxygen makeup requirements. Although all of the electrochemical concepts identified and evaluated are complex bulky subsystems, the hydrogen depolarized cell concept and the fused salt concept offer some unique advantages when combined into a totally regenerable CO_2 control/O_2 supply subsystem and were carried forward for further evaluation.



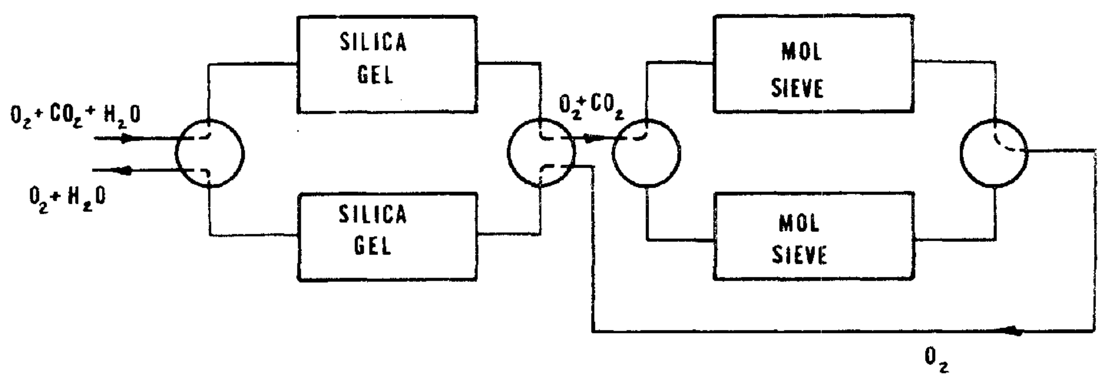
AEPS WT	AEPS POWER	VEHICLE IMPACT
111	2.4 CREDIT	7760

FIGURE 2–30. PURGE FLOW



AEPS WT	AEPS POWER	VEHICLE IMPACT
168	5.6	67+

FIGURE 2-31. MOLECULAR SIEVE — PART CYCLIC



AEPS WT	AEPS POWER	VEHICLE IMPACT
71	8.2	98

FIGURE 2-32. MOLECULAR SIEVE — CYCLIC

TABLE 2-8
CARBON DIOXIDE CAPACITIES OF GROUP IA AND IIA METAL OXIDES

Oxides	Formula Weight	Lbs. CO_2/Lbs. Oxide	Lbs. Oxide/Lb. CO_2 Lbs.
Li_2O	29.88	1.473	0.679
Na_2O	61.98	0.710	1.409
K_2O	94.20	0.467	2.141
MgO	40.32	1.091	0.915
CaO	56.08	0.785	1.275
SrO	103.36	0.425	2.355
BaO	153.36	0.287	3.485

Assumed reaction - M^{I}_2O or $M^{II}O + CO_2 \longrightarrow M^{I}_2CO_3$ or $M^{II}CO_3$.

TABLE 2-9
THERMODYNAMIC STABILITIES OF GROUP I AND II METAL CARBONATES

($\Delta F°$ refers to the reaction $M^{I}_2CO_3$ or $M^{II}CO_3 \longrightarrow M^{I}_2O$ or $M^{II}O + CO_2$ at 25°C.)

Metal Carbonate	$\Delta F°$, kcals./mole
Li_2CO_3	+ 42.56
Na_2CO_3	+ 67.1
K_2CO_3	+ 81.9
Rb_2CO_3	+ 79.1
Cs_2CO_3	+ 79.9
$CuCO_3$	- 0.9
Ag_2CO_3	+ 7.3
$MgCO_3$	+ 15.9
$CaCO_3$	+ 31.3
$SrCO_3$	+ 43.8
$BaCO_3$	+ 50.0
$ZnCO_3$	+ 4.4
$CdCO_3$	+ 11.5

TABLE 2-10
CYCLIC SUBSYSTEMS

SORBENT	AEPS WT	AEPS POWER	VEHICLE IMPACT
ACTIVATED CHARCOAL	139	1.8	4240
MOLECULAR SIEVE	71	8.2	98
Ag_2O	28	4.2	1890
ZnO	10	7.0	83
SOLID AMINE	21	.2	3

TABLE 2-11
NONCYCLIC SUBSYSTEMS

SORBENT	AEPS WT	AEPS POWER	VEHICLE IMPACT
ACTIVATED CHARCOAL	615	.2	3
MOLECULAR SIEVE	168	5.6	67
Ag_2O	116	.2	1556
ZnO	19	.2	83
SOLID AMINE	87	.2	3

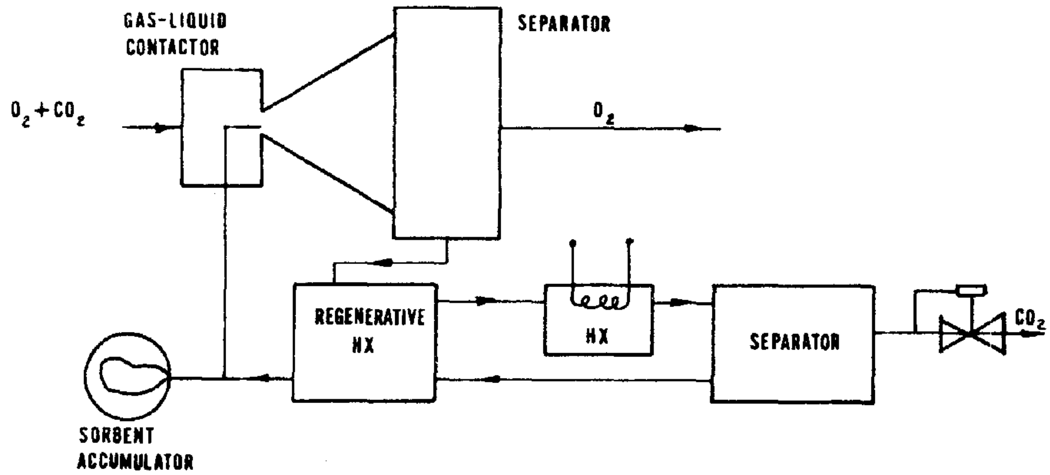


FIGURE 2-33. LIQUID SORBENT – AEPS REGENERABLE

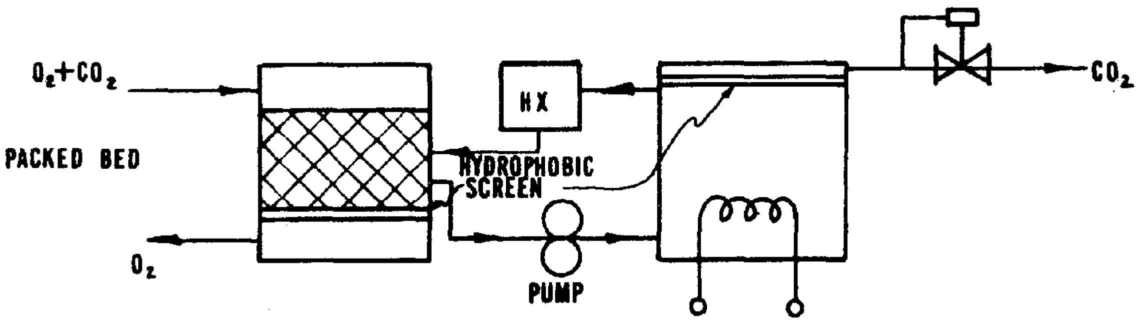
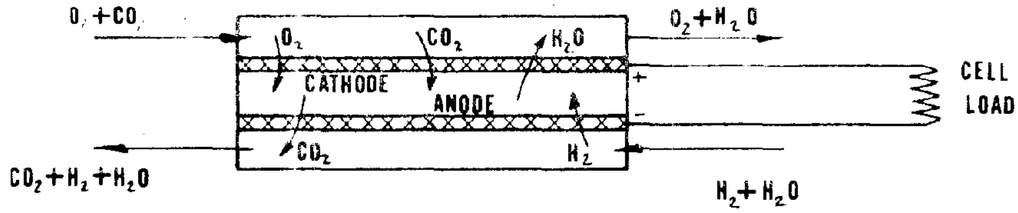


FIGURE 2–34. LIQUID SORBENT – AEPS REGENERABLE

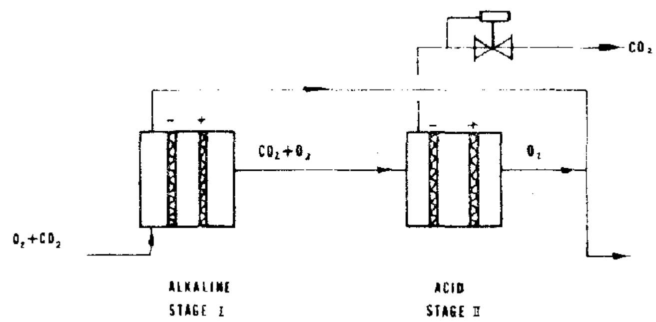
TABLE 2–12
REGENERABLE LIQUID SORBENTS

SORBENT	OPERATIONAL MODE	AEPS WT	AEPS POWER	VEHICLE IMPACT
K_2CO_3	CYCLIC	18	24.6	320
K_2CO_3	NON CYCLIC	163	0.2	920
PEI	CYCLIC	15	4.9	59
PEI	NON CYCLIC	41	0.2	160



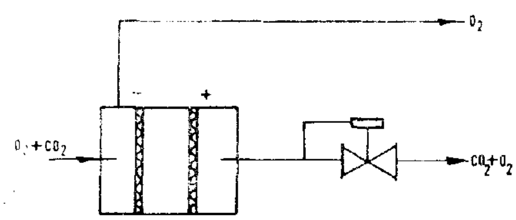
AEPS WT	AEPS POWER	VEHICLE IMPACT
59	1.3	163+

FIGURE 2-35.HYDROGEN DEPOLARIZED CELL



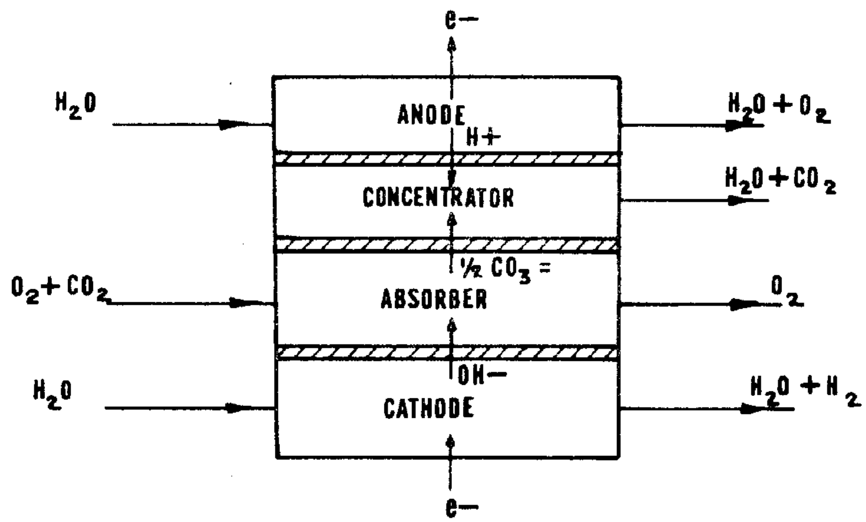
AEPS WT	AEPS POWER	VEHICLE IMPACT
44	40	480+

FIGURE 2-36. TWO-STAGE CARBONATION CELL



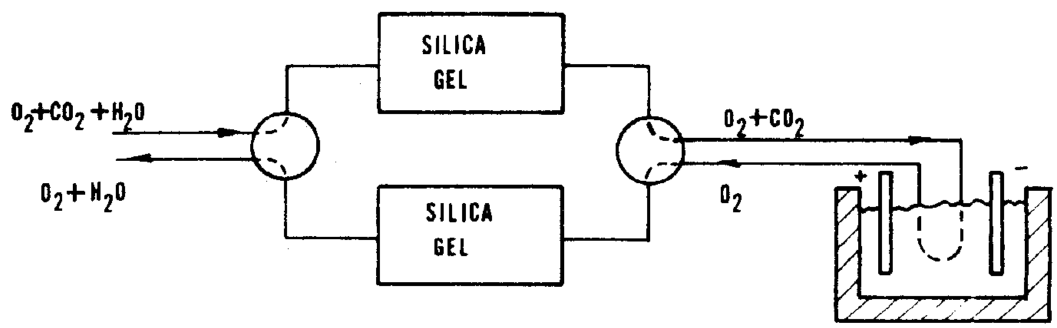
AEPS WT	AEPS POWER	VEHICLE IMPACT
27	24.6	590+

FIGURE 2-37. SINGLE-STAGE CARBONATION CELL



AEPS WT	AEPS POWER	VEHICLE IMPACT
67	48	572

FIGURE 2–38. ELECTRODIALYSIS



	AEPS WT	AEPS POWER	VEHICLE IMPACT
CYCLIC	53	62	525+
NON-CYCLIC	56	4.5	155+

FIGURE 2–39. FUSED SALT

2.1.3.4 Mechanical - Mechanical CO_2 control concepts identified and evaluated are classified into two categories: (1) membrane diffusion and (2) freezeout. Figure 2-40 depicts a simple membrane diffusion concept utilizing a CO_2 permeable cellulose acetate membrane. A complex but more efficient concept is the immobilized liquid membrane diffusion concept shown in Figure 2-41. Mechanical freezeout and cryogenic freezeout concepts are presented in Figures 2-42 and 2-43, respectively. All four concepts appear to be too heavy and bulky to be competitive.

2.1.3.5 Summary - The CO_2 control subsystem concepts selected for further evaluation are:

a. LiOH
b. Cooled LiOH
c. Li_2O_2
d. Molecular Sieve - AEPS Regenerable
e. MgO - Vehicle Regenerable
f. MgO - AEPS Regenerable
g. ZnO - Vehicle Regenerable
h. ZnO - AEPS Regenerable
i. Solid Amine - AEPS Regenerable
j. Aqueous K_2CO_3 - AEPS Regenerable
k. Liquid Amine (PEI) - AEPS Regenerable
l. H_2 Depolarized Cell
m. Fused Salt

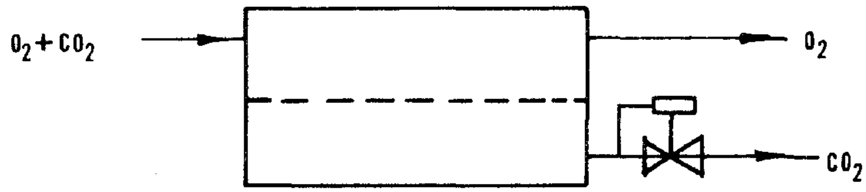
2.1.4 Oxygen Supply

The O_2 supply subsystem maintains AEPS pressure and provides oxygen makeup for crewman metabolic consumption and AEPS external leakage. Twelve candidate oxygen supply concepts were considered in the four basic categories of:

a. Oxygen Storage
b. Solid Decomposition
c. Liquid Decomposition
d. Water Electrolysis

2.1.4.1 Oxygen Storage - Oxygen may be stored as a gas, liquid or solid. Gaseous storage is presented in Figure 2-44 for both 3000 and 6000 psi storage.

Oxygen may also be stored in the form of a cryogenic liquid. Supercritical and subcritical storage utilizing thermal pressurization are depicted in Figures 2-45 and 2-46 while subcritical storage utilizing positive expulsion is shown in Figure 2-47. While the weight and bulk of the gaseous and cryogenic liquid concepts are very similar, the cryogenic concepts are more complex. In addition, the mission vehicles in the 1980's are not projected to provide cryogenic storage of oxygen.



AEPS WT	AEPS POWER	VEHICLE IMPACT
400	0.2	4+

FIGURE 2-40. MEMBRANE DIFFUSION

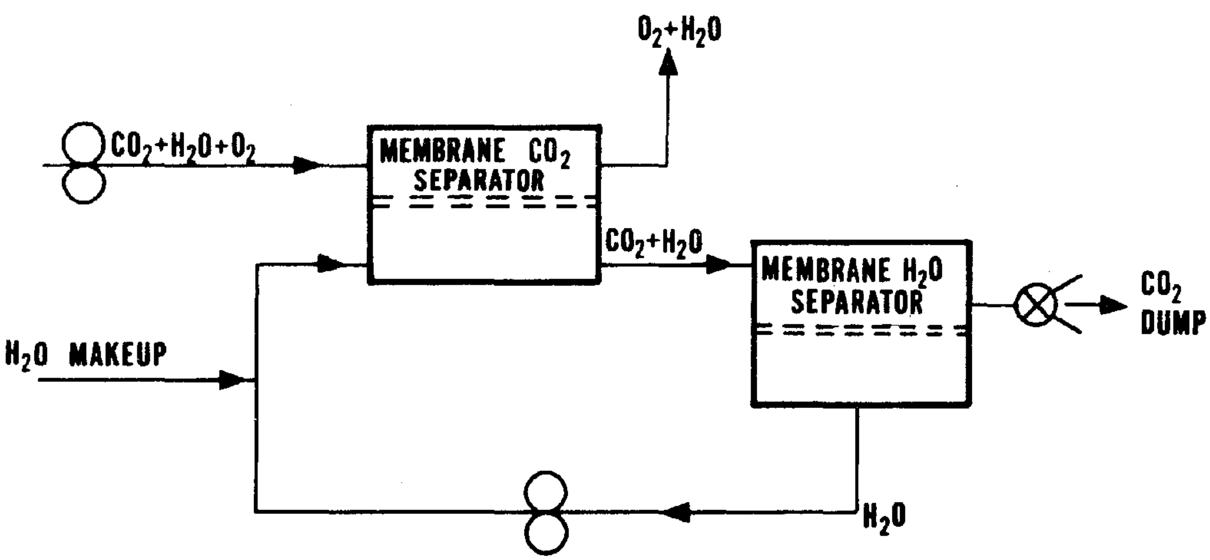
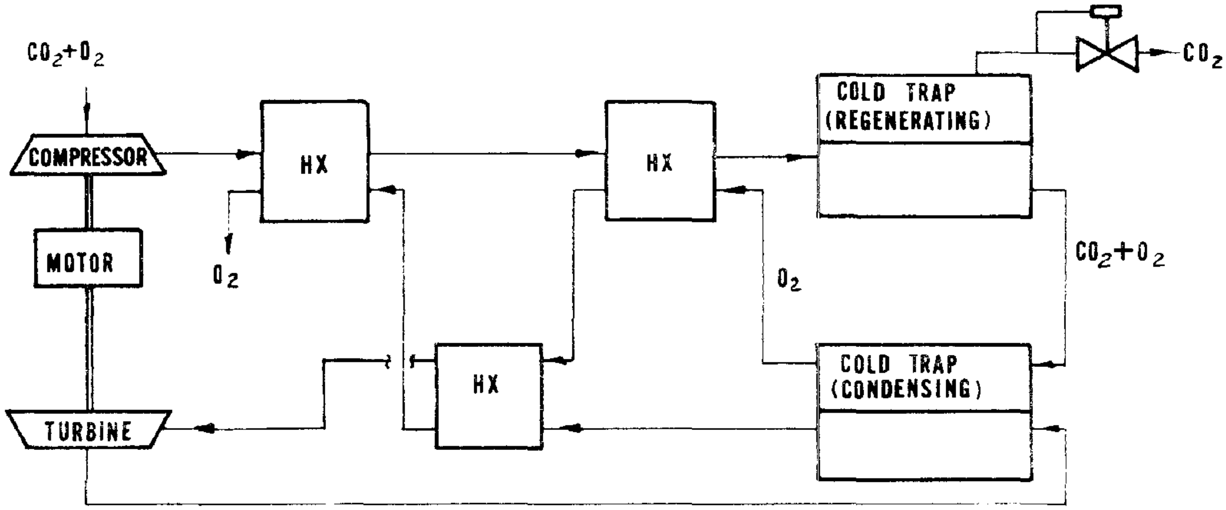
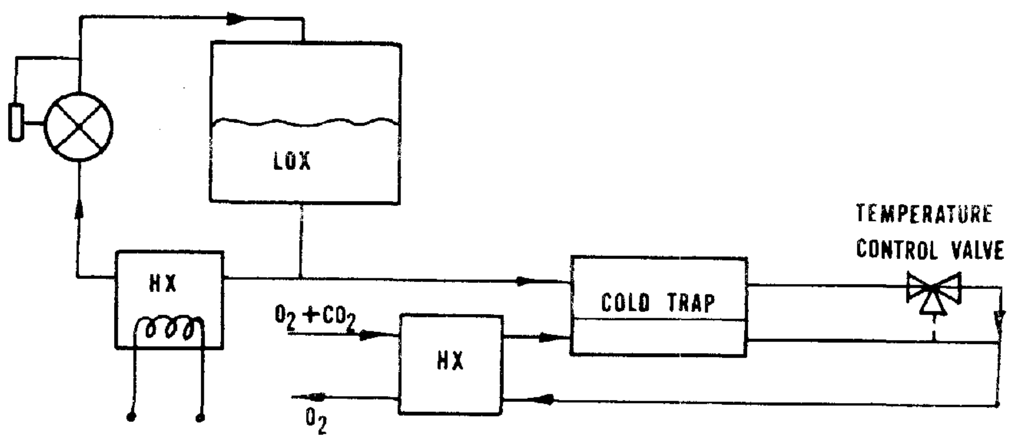


FIGURE 2-41. IMMOBILIZED LIQUID MEMBRANE DIFFUSION



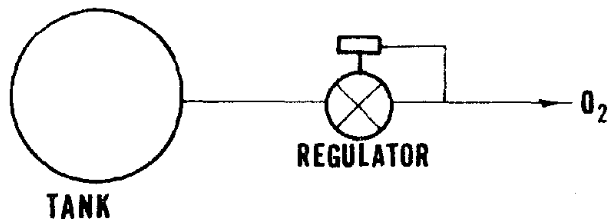
AEPS WT	AEPS POWER	VEHICLE IMPACT
165	15	540+

FIGURE 2-42. MECHANICAL FREEZEOUT



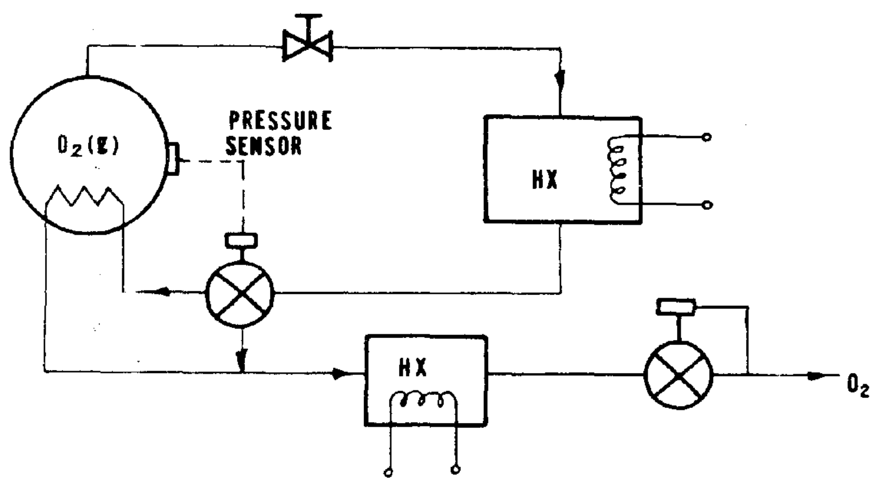
	AEPS WT	AEPS POWER	VEHICLE IMPACT
CO_2	51	6	1640
CO_2/H_2O	147	—	12100

FIGURE 2-43. CRYOGENIC FREEZEOUT



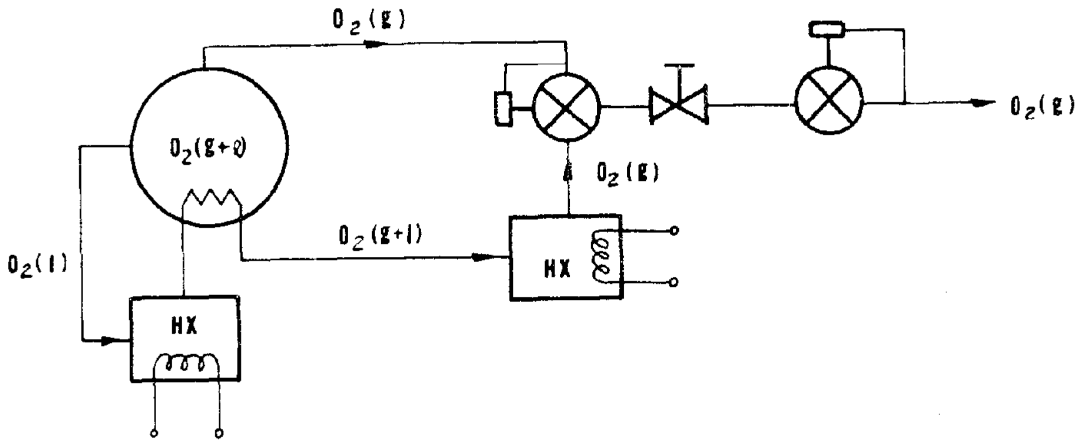
PRESSURE LEVEL	AEPS WT	AEPS POWER	VEHICLE IMPACT
3000 psi	6.8	—	279 +
6000 psi	7.3	—	279 +

FIGURE 2–44. GASEOUS O_2 STORAGE



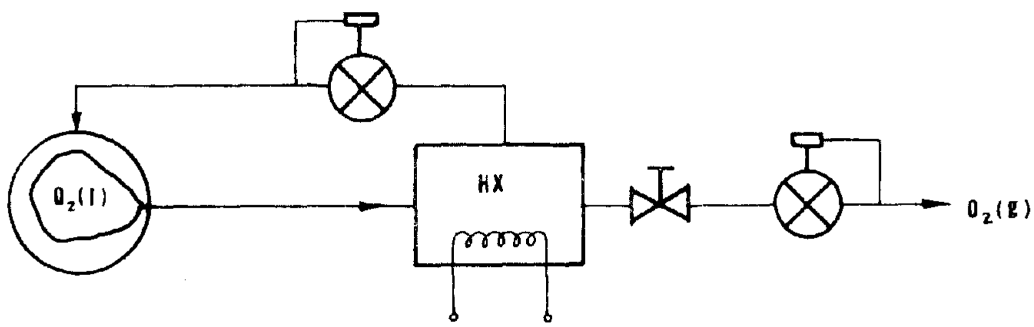
AEPS WT	AEPS POWER	VEHICLE IMPACT
9	—	289 +

FIGURE 2–45. SUPERCRITICAL CRYOGENIC STORAGE – THERMAL PRESSURIZATION



AEPS WT	AEPS POWER	VEHICLE IMPACT
8	0	289 +

FIGURE 2-46. SUBCRITICAL CRYOGENIC STORAGE – THERMAL PRESSURIZATION



AEPS WT	AEPS POWER	VEHICLE IMPACT
9	–	289 +

FIGURE 2-47. SUBCRITICAL CRYOGENIC STORAGE – POSITIVE EXPULSION

2.1.4.1 (Continued)

Solid oxygen storage is schematically depicted in Figure 2-48. Due to the extremely low temperature of solid O_2 storage, complex interfaces and operating procedures are required, thus making this concept very unattractive.

2.1.4.2 Solid Decomposition - Oxygen may be stored in the form of a solid chemical and supplied as required to repressurize storage tankage or a depressurized cabin, as depicted in Figure 2-49. This concept, due to the constant supply rate of the ignited chemical, must either be designed for the maximum oxygen usage required during the mission or include tankage and sequential ignition control of multiple candles; thus this concept is two to three times the gaseous storage concept AEPS weight and vehicle impact and is not competitive.

2.1.4.3 Liquid Decomposition - Figure 2-50 shows oxygen stored in the form of hydrogen peroxide. This system was sized to provide the oxygen required for metabolic consumption and AEPS external leakage (versus the same system depicted in Figure 2-12 which was sized primarily to provide thermal control). The liquid water formed as a result of the H_2O_2 decomposition is fed to the expendable water thermal control system to provide supplemental cooling. This concept is only competitive if it is integrated with an expendable water thermal control subsystem.

Another oxygen supply candidate utilizing liquid decomposition is reactant storage (Figure 2-51). This concept would only be considered if a two-gas AEPS system is required.

2.1.4.4 Water Electrolysis - Oxygen supply utilizing water electrolysis is presented in Figure 2-52. This concept will only be considered for oxygen supply in a totally regenerable AEPS configuration in conjunction with a CO_2 reduction subsystem producing water.

2.1.4.5 Summary - Results of this preliminary evaluation indicate gaseous oxygen storage is the simplest subsystem concept and has minimum bulk and minimum vehicle impact. In addition, it is the only candidate concept which has the capability to rapidly provide oxygen in the event of an emergency decompression of the AEPS. An evaluation to optimize the gaseous storage pressure level will be conducted during the system integration studies.

2.1.5 Oxygen Generation

The oxygen generation subsystem reduces the concentrated carbon dioxide input and generates oxygen to provide for crewman metabolic consumption and AEPS external leakage. Three oxygen generation concepts were investigated and evaluated for utilization in a totally regenerable AEPS configuration:

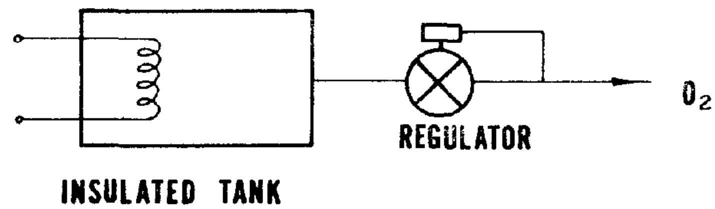
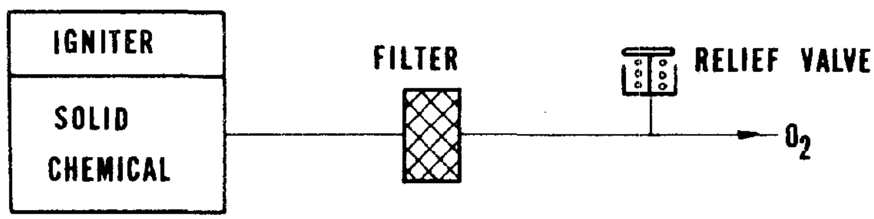
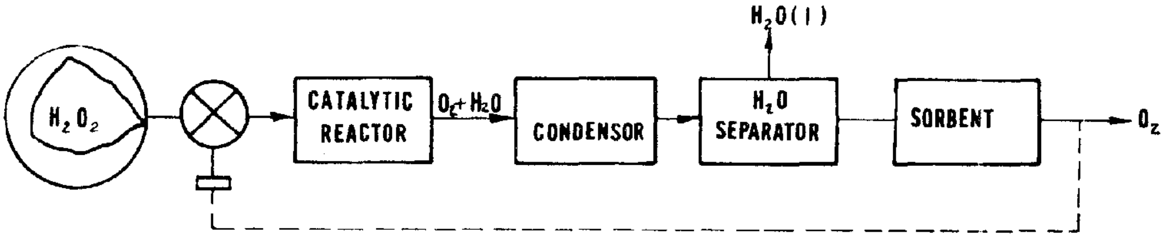


FIGURE 2-48. SOLID O_2 STORAGE



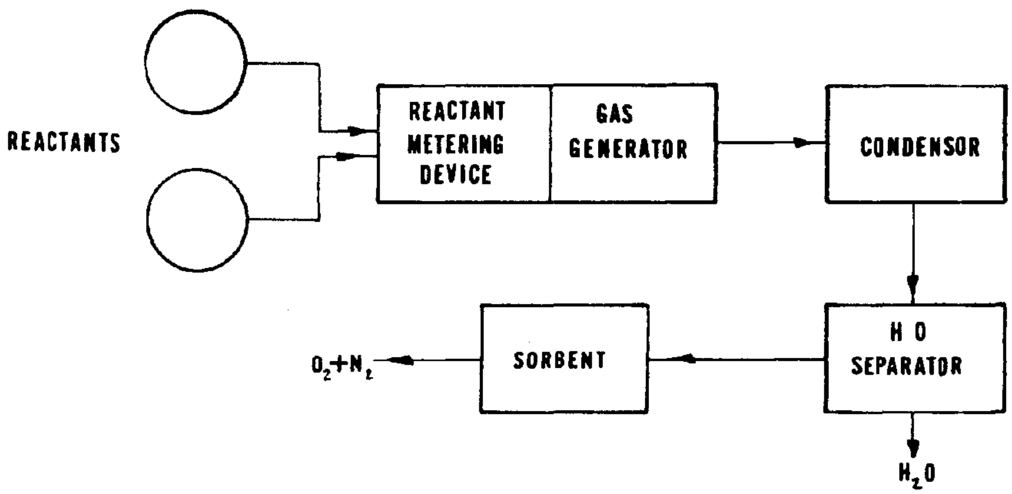
CHEMICAL	AEPS WT	AEPS POWER	VEHICLE IMPACT
$NaClO_3$	20	-	794 +
$LiClO_4$	17	-	613 +

FIGURE 2-49. SOLID CHEMICAL STORAGE



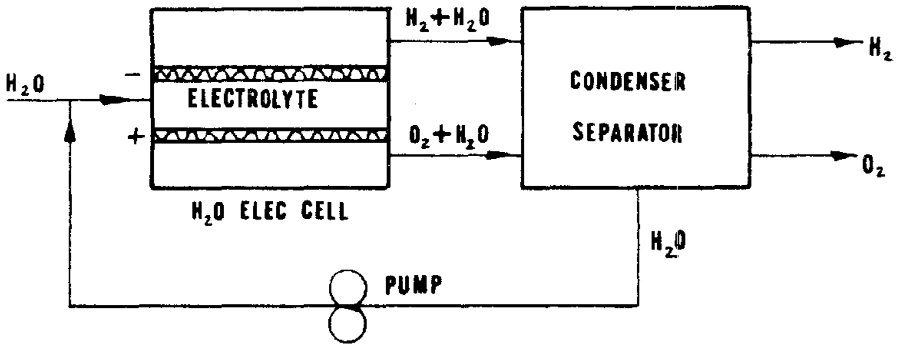
AEPS WT	AEPS POWER	VEHICLE IMPACT
13	0.2	675 +

FIGURE 2–50. HYDROGEN PEROXIDE (H_2O_2)



REACTANTS	AEPS WT	AEPS POWER	VEHICLE IMPACT
N_2H_4/N_2O_4	38	—	792 +
N_2H_4/H_2O_2	39	—	861 +

FIGURE 2–51. REACTANT STORAGE



AEPS WT	AEPS POWER	VEHICLE IMPACT
53	51	924 +

FIGURE 2-52. WATER ELECTROLYSIS

2.1.5 (Continued)

a. Solid Electrolyte (Figure 2-53)
b. Bosch Reactor/Water Electrolysis (Figure 2-54)
c. Sabatier Reactor/Water Electrolysis (Figure 2-55)

All three concepts are too bulky to be worn or carried by the crewman, but could be carried on a cart and connected to the crewman via umbilicals. To ensure further consideration of total regenerable CO_2 control/O_2 supply concepts, the solid electrolyte and Sabatier reactor/water electrolysis concepts were carried forward for further evaluation while the Bosch reactor/water electrolysis concept, due to its larger bulk and severe carbon handling problem, was eliminated from further consideration.

2.1.6 Combined CO_2 Control/O_2 Supply

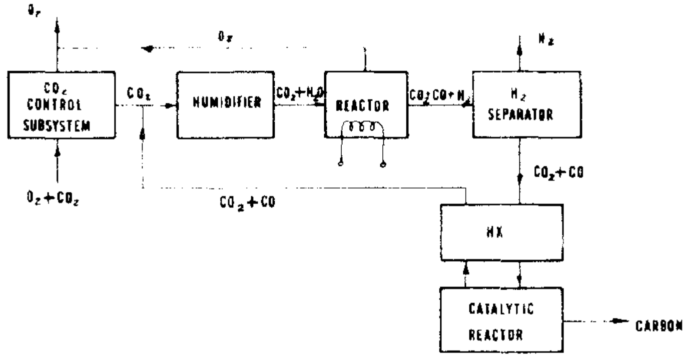
The CO_2 control, O_2 supply and O_2 generation concepts selected for further evaluation were combined in accordance with the scheme defined in Table 2-13 to permit evaluation of expendable, partially regenerable, and totally regenerable CO_2 control/O_2 supply subsystems during the remainder of the subsystems studies effort. Subsystem functions are defined in the top column; subsystem type and where the regeneration is performed is defined in the left-hand column; and each individual box defines where the specific function is accomplished -- on the AEPS or in the vehicle.

2.1.7 Contaminant Control

The contaminant control subsystem maintains the concentration of trace gases, biological micro-organisms, and particulate matter at acceptable levels so that the health and comfort of the crewman is safeguarded.

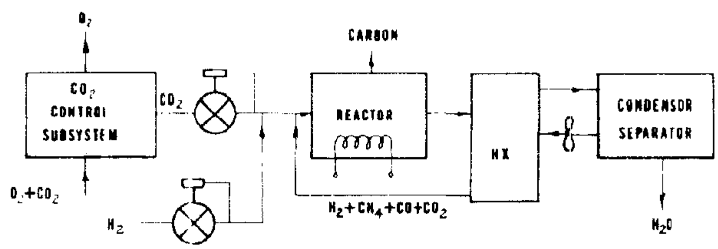
In order to adequately design a contaminant control subsystem for the AEPS, it is necessary to define a model of the contaminant atmosphere. The choice of contaminants in the model will be made principally from those known to be biologically generated. In addition to a list of contaminants, the model will also include generation rates and maximum allowable concentrations.

Determination of the AEPS contaminant model is dependent upon final selection of AEPS subsystems and componentry. Therefore, we have chosen only to identify the candidate contaminant control subsystem concepts during this phase of the study and to postpone definition of the contaminant model and subsequent evaluation and selection of the candidate concepts until the system studies.



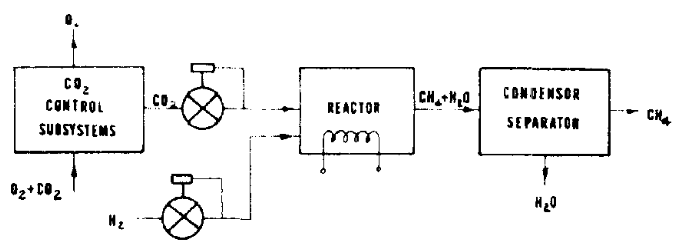
AEPS WT	AEPS POWER	VEHICLE IMPACT
80	41	614+

FIGURE 2–53. SOLID ELECTROLYTE



AEPS WT	AEPS POWER	VEHICLE IMPACT
47	9.6	141+

FIGURE 2–54. BOSCH REACTOR



AEPS WT	AEPS POWER	VEHICLE IMPACT
14	1.4	16+

FIGURE 2–55. SABATIER REACTOR – METHANE DUMP

TABLE 2–13
COMBINED CO_2/O_2

TYPE	CO_2 REMOVAL	CO_2 CONCENTRATION	CO_2 REDUCTION	O_2 GENERATION	O_2 SUPPLY
1. EXPENDABLE	AEPS	–	–	–	AEPS
2. PART REGEN-AEPS	AEPS	–	–	–	AEPS
3. PART REGEN-VEHICLE	AEPS	–	–	–	AEPS
4. REGENERABLE-VEHICLE	AEPS	VEHICLE	VEHICLE	VEHICLE	AEPS
5. REGENERABLE-AEPS & VEHICLE	AEPS	AEPS	VEHICLE	VEHICLE	AEPS
6. REGENERABLE-AEPS & VEHICLE	AEPS	AEPS	AEPS	VEHICLE	AEPS
7. REGENERABLE-AEPS	AEPS	AEPS	AEPS	AEPS	–

2.1.7 (Continued)

The candidate contaminant control subsystem concepts identified are as follows:

a. Trace gases -

1) Membrane separation
2) Physical adsorption
3) Chemical absorption
4) Conversion to non-contaminating constituents
5) Conversion to a more easily controllable contaminant

b. Biological microorganisms -

1) Filtration
2) Electrostatic precipitation
3) Impingement
4) Air centrifuge
5) Electrophoresis

c. Particulate matter

1) Filtration
2) Debris trap

2.1.8 Power

A general survey of power subsystems was conducted resulting in the identification of 52 specific candidate concepts within the following basic categories:

a. Nuclear Energy through -

1) Fusion
2) Fission
3) Radioisotope

b. Solar Energy

c. Chemical Energy utilizing -

1) N_2H_4
2) H_2O_2
3) $Li + F_2$

d. Electrochemical

1) Fuel cell
2) Battery

e. Mechanical Energy through -

1) Flywheel
2) Spring
3) Crewman power

Selection of a power subsystem concept is heavily dependent upon the required power capacity for a given mission duration. Since the required power capacity had not yet been defined for the AEPS, the preliminary evaluation was only a cursory one.

AEPS subsystems and components which may require electrical power are:

a. Communications and telemetry
b. Instrumentation and displays
c. Prime movers
d. CO_2 control/O_2 supply subsystem
e. Thermal control subsystem
f. Humidity control subsystem

Once the CO_2 control/O_2 supply, thermal control and humidity control subsystems are selected, the AEPS power requirement may be defined and a power subsystem selected. For the purposes of the remaining subsystem studies, the AEPS power supply was assumed to be a lithium-nickel halide battery with a power penalty of 100 watt-hours per pound. This selection will be updated and revised, as required, during the systems studies.

2.2 PHASE TWO EFFORT

The primary objectives of Phase Two of the AEPS Study were to provide a meaningful appraisal of (1) portable life support concepts for EVA use on potential Space Shuttle missions in the late 1970's and of (2) emergency portable life support concepts for EVA use on potential Space Station, Lunar Base, Mars Landing and Shuttle missions for use in the time frames established by this study for each of the respective primary portable life support systems.

2.2.1 Shuttle AEPS

The initial candidate concept identification and evaluation effort conducted during Phase Two utilized the results of the Phase One effort as a baseline. Our experience during Phase One permitted us to be more discriminating in the selection of candidate subsystem concepts to be carried into the Go/No Go Evaluation. Of the following nine candidate thermal control subsystem concepts selected to be carried into the Go/No Go Evaluation, only the vehicle umbilical concept had not been previously evaluated.

a. Water Boiler
b. Water Sublimator
c. Cryogenic O_2
d. Thermal Storage - PH_4Cl
e. Thermal Storage - Ice
f. Expendable/Radiation - Heat Pump
g. Expendable/Thermal Storage - PH_4Cl
h. Vehicle Umbilical
i. Cryogenic H_2

Seven candidate CO_2 control sybsystem concepts were selected to be carried into the Go/No Go Evaluation. Of the following concepts, only the two vehicle umbilical concepts and the vehicle regenerable metal hydroxide concept were not previously evaluated:

a. LiOH
b. Li_2O_2
c. Purge Flow - Vehicle Umbilical
d. Demand Flow - Vehicle Umbilical
e. Metallic Oxide
f. Solid Amine
g. Metal Hydroxide

2.2.1 (Continued)

A schematic of the vehicle regenerable metal hydroxide concept is shown in figure 2-56.

Four candidate O_2 supply subsystem concepts were selected to be carried into the Go/No Go Evaluation. Of the following concepts, only the vehicle umbilical concept was not previously evaluated.

a. Gaseous Storage
b. $NaClO_3$
c. Vehicle Umbilical
d. H_2O_2 (with maneuvering only)

2.2.2 Emergency Systems

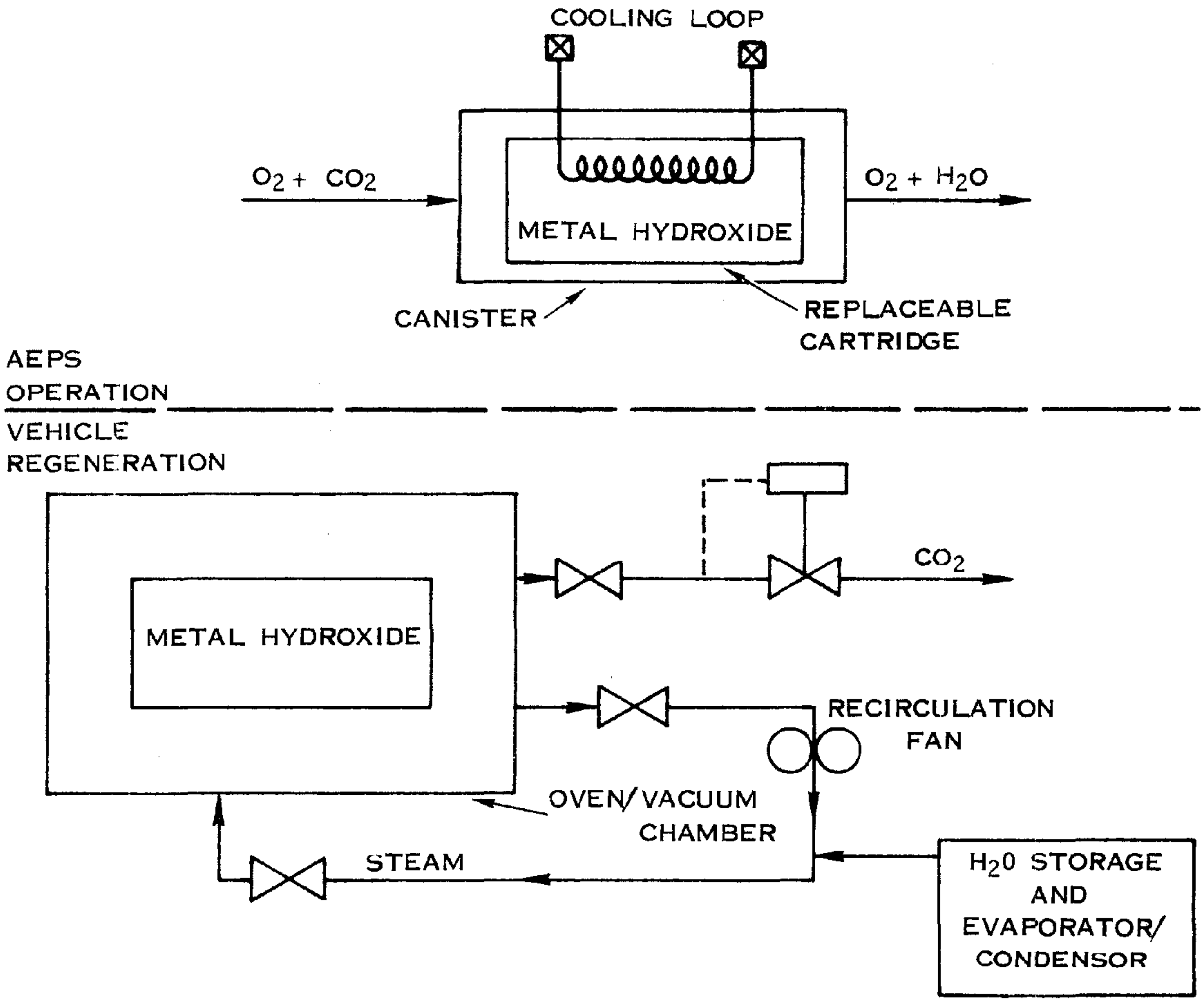
As with the Shuttle AEPS effort, the initial emergency system subsystem concept identification and evaluation effort utilized the results of the Phase One effort as a baseline. The candidate thermal control subsystem concepts carried into the Go/No Go Evaluation were:

a. Water Boiler
b. Water Sublimator
c. Thermal Storage - PH_4Cl
d. Thermal Storage - Eutectic Salt
e. Thermal Storage - Ice
f. Redundant Primary System
g. Vehicle Umbilical

Only the redundant primary system and the vehicle umbilical concepts had not been previously evaluated.

The following candidate CO_2 control subsystem concepts were carried into the Go/No Go Evaluation:

a. Metal Oxides
b. Li_2O_2
c. Metal Hydroxides
d. LiOH
e. KO_2
f. Solid Amine
g. Vehicle Umbilical
h. Purge Flow



$$MCO_3 \xrightarrow[\text{VACUUM}]{\text{HEAT}} MO + CO_2$$

$$MO + H_2O \longrightarrow M(OH)_2$$

FIGURE 2–56. METAL HYDROXIDE – VEHICLE REGENERABLE

2.2.2 (Continued)

The following candidate O_2 supply subsystem concepts were carried into the Go/No Go Evaluation:

a. Gaseous Storage
b. $NaClO_3$ Candle
c. Li_2O_2
d. KO_2
e. Vehicle Umbilical

Only the vehicle umbilical CO_2 control and O_2 supply concepts had not been previously evaluated.

3.0 GO/NO GO EVALUATION

3.0 GO/NO GO EVALUATION

3.1 Go/No Go Evaluation Criteria

The determination of the AEPS Study selection criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others are secondary in that they are desirable but not absolutely necessary. The criteria used as a basis for the primary AEPS subsystem selections are shown in Figure 3-1. The criteria are applied sequentially in the groups shown to eliminate concepts that fail in either an absolute (go/no go) or comparative basis and to provide the basis for selection between surviving candidates.

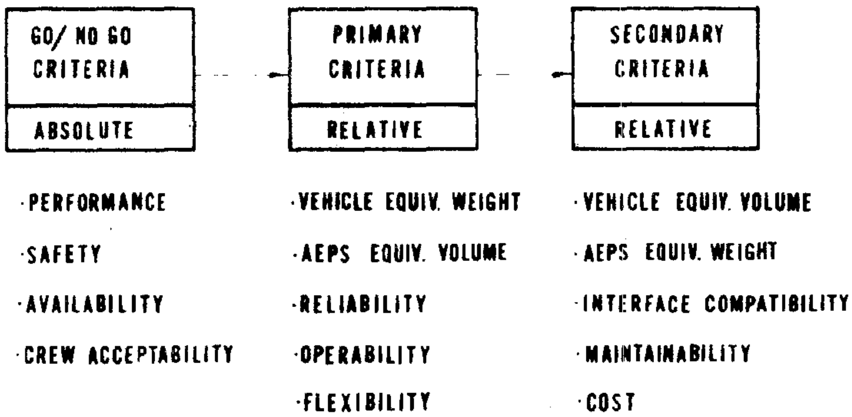


FIGURE 3-1. PRIMARY AEPS EVALUATION CRITERIA

The criteria used as a basis for the AEPS Emergency System subsystem selections are shown in Figure 3-2. The selection criteria for the Emergency System subsystem concepts were reevaluated and revised due to the nature and manner of use of emergency systems (versus the primary life support system). Note however that the go/no go evaluation criteria is unchanged.

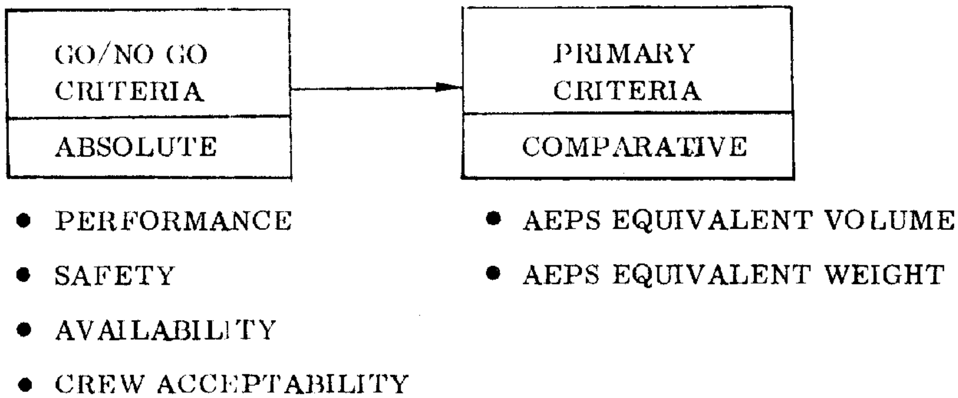


FIGURE 3-2. EMERGENCY SYSTEM EVALUATION CRITERIA

Go/no go criteria define the minimum acceptable requirements for a concept. If a concept does not meet or cannot be modified to meet all of the go/no go criteria, no further consideration is given to that concept and it is eliminated. The go/no go criteria are listed as follows:

Performance - All concepts must be capable of meeting the entire performance specification to be considered as candidates. To provide a common basis, conceptual designs are adjusted for each competing subsystem, system, or method to meet the same performance requirements.

Safety - Safety of each concept is evaluated with respect to fire, contamination, explosion hazards, hot spots, bacteriological problems, and crew hazards to determine if any of these are present which cannot be eliminated by careful design or inclusion of additional control equipment, different materials, etc. Hazards are investigated during normal operation and off-design operation. If any serious problems are discovered which cannot be reasonably avoided, the concept is eliminated.

Availability - Availability is a measure of the probability of a concept being fully operational within the required time period (following reasonable development effort). Preliminary screening of concepts eliminates many questionable concepts where feasibility has not been convincingly established. Availability is evaluated by an analysis of the subsystem approach, its interfaces and hardware requirements to

TABLE 3-1. GO/NO GO EVALUATION - THERMAL CONTROL (SPACE STATION, LUNAR BASE & MARS)

	CONCEPT	CRITERIA				REMARKS
		PERFORMANCE	CREW ACCEPTABILITY	SAFETY	AVAILABILITY	
1.	H_2O Boiler	P	P	P	P	Accept
2.	Supercooled H_2O Boiler	F	P	M	P	Reject
3.	H_2O Sublimator	P	P	P	P	Accept
4.	Supercooled H_2O Sublimator	F	P	M	P	Reject
5.	Plate-Fin Flash Evaporator	P	P	P	P	Accept
6.	Rotary Flash Evaporator	P	P	P	P	Accept
7.	Vapor Diffusion thru Suit Valves	P	M	P	P	Accept*
8.	Radiation Direct Cooling	P	M	P	P	Accept*
9.	Freon Refrigeration Cycle	P	M	P	P	Accept*
10.	H_2O Adsorption - $CaCl_2$	M	M	P	P	Use as backup for 11.
11.	H_2O Adsorption - LiBr	M	M	P	P	Accept*
12.	H_2O Adsorption - Na_2Se	M	M	P	P	Use as backup for 11.
13.	Thermal Storage - Ice	P	P	P	P	Accept
14.	Thermal Storage - Subcooled Ice	P	P	P	P	Accept
15.	Thermal Storage - PH_4Cl	P	M	M	P	Accept*
16	Thermal Storage - H_2	F	M	M	P	Reject
17.	Expend/Rad - Direct Cooling	P	P	P	P	Accept
18.	Expend/Rad - Heat Pump	P	P	P	P	Accept
19.	Expend/Therm Storage - Ice	P	P	P	P	Accept
20.	Expend/Therm Storage - PH_4Cl	P	M	M	P	Accept*
21.	Rad/Therm Storage - Ice	P	P	P	P	Accept
22.	Rad Therm Storage - PH_4Cl	P	P	M	P	Accept*
23.	Therm Stor - PH_4Cl/Adsorp - $CaCl_2$	M	M	P	P	Use as backup for 25.
24.	Therm Stor - PH_4Cl/Adsorp - LiBr	M	M	P	P	Use as backup for 25.
25.	Therm Stor - PH_4Cl/Adsorp - Na_2Se	M	M	P	P	Accept*

P = Pass

F = Fail

M = Marginal

* = Marginal Acceptance

TABLE 3-2. GO/NO GO EVALUATION - CO_2 CONTROL/O_2 SUPPLY (SPACE STATION, LUNAR BASE & MARS)

	CONCEPT	CRITERIA				REMARKS
		PERFORMANCE	CREW ACCEPTABILITY	SAFETY	AVAILABILITY	
1.	LiOH	P	P	P	P	Accept
2.	Cooled LiOH	P	P	P	P	Accept
3.	Li_2O_2	P	P	P	P	Accept
4.	Molecular Sieve - AEPS Regen	F	P	P	P	Reject
5.	MgO - Vehicle Regen	P	P	P	P	Accept
6.	MgO - AEPS Regen	P	P	P	P	Accept
7.	ZnO - Vehicle Regen	P	P	P	P	Accept
8.	ZnO - AEPS Regen	P	P	P	P	Accept
9.	Solid Amine (SBT) - AEPS Regen	P	P	P	P	Accept
10.	Aqueous K_2CO_3 - AEPS Regen	P	P	P	P	Use as backup for 11.
11.	Liquid Amine (PEI) - AEPS Regen	P	P	P	P	Accept
12.	Solid Electrolyte	M	M	M	P	Accept*
13.	Fused Salt	M	M	M	M	Reject
14.	H_2 Depol. Cell/Sabatier H_2O Elec	M	M	P	P	Accept*
15.	H_2 Depol. Cell/CO_2 Conc H_2O Elec	M	M	P	P	Accept*
16.	H_2 Depol. Cell Sabatier H_2O Accum	M	M	P	P	Accept*
17.	H_2 Depol. Cell CO_2 Conc O_2 Supply	M	M	P	P	Accept*
18.	CO_2 Cont/Sabatier/Wick Feed H_2O Elec	M	M	P	P	Accept*
19.	CO_2 Cont Sabatier Solid Polymer H_2O Elec	M	M	P	P	Accept*

P = Pass

F = Fail

M = Marginal

* Marginal Acceptance

define problem areas and design "qualms". These are classified into state-of-the-art (advanced technology) versus design/development type problems and estimates made of schedule requirements for technology advance and development improvements.

Crew Acceptability - This is a measure of the psychological acceptability of the approach by the eventual user. The equipment must be designed to assure that it imposes a minimal operational stress on the crew. If a concept is deemed to be unacceptable by the crew and cannot be corrected, that concept is eliminated. Examples of potential marginal areas where crew acceptability may be an overriding criteria are the use of a radioactive power source, location of controls and displays, specific EVA operational procedures, etc. If a "marginal" concept does pass the go/no go test, it will be highlighted as "marginal" to ensure further consideration of this criterion during later stages of the evaluation.

3.2 Phase One Go/No Go Evaluation Results

Effort during the initial concept of identification phase of the subsystem studies conducted during phase one of the study culminated in the selection of thermal control and CO_2 control/O_2 supply subsystem candidate concepts to be carried into the go/no go evaluation. Of the original 55 thermal control concepts identified and analyzed on a preliminary basis, 25 were carried into the go/no go evaluation; of the original 45 combined CO_2 control/O_2 supply concepts identified and analyzed on a preliminary basis, 19 were carried into the go/no go evaluation.

Performance characteristics (such as flow rates, temperature levels and pressure levels) of the selected candidate subsystems to be carried into the go/no go evaluation were roughly determined and the preliminary schematics and component lists were updated. These subsystems were then compared against the go/no go evaluation criteria. A summary of the results of the go/no go evaluation is presented in Tables 3-1 and 3-2. Of the 25 thermal control concepts evaluated, 18 concepts passed the go/no go evaluation, four were selected as backup concepts, and three were eliminated from further consideration; of the 19 CO_2/O_2 supply concepts evaluated, 16 concepts passed the go/no go evaluation, one was selected as a backup concept, and two were eliminated from further consideration.

Note that the concepts which were deemed marginal with respect to a given criteria were not rejected, but the marginal area was noted to ensure further consideration during the system studies if the concept should pass both the primary and secondary evaluation.

3.3 PHASE TWO GO/NO GO EVALUATION RESULTS

Effort during the initial concept and identification phase of the subsystem studies conducted during phase two culminated in the selection of 9 thermal control, 7 CO_2 control and 4 O_2 supply shuttle AEPS subsystem concepts to be carried into the go/no go evaluation and 7 thermal control, 10 CO_2 control and 4 O_2 supply emergency system subsystem concepts to be carried into the go/no go evaluation.

Performance characteristics of the selected candidate subsystems to be carried into the go/no go evaluation were roughly determined. These subsystems were then compared against the go/no go evaluation criteria. A summary of the results of the go/no go evaluation are presented in Tables 3-3 through 3-8.

TABLE 3-3. GO/NO GO EVALUATION - THERMAL CONTROL (SHUTTLE)

Concept	Criteria				Remarks
	Performance	Crew Acceptability	Safety	Availability	
1. H_2O Boiler	P	P	P	P	Accept
2. H_2O Sublimator	P	P	P	P	Accept
3. Cryogenic O_2	F	M	M	P	Reject
4. Thermal Storage - PH_4Cl	P	M	M	P	Accept*
5. Thermal Storage - Ice	P	P	P	P	Accept
6. Expend/RAD-Heat Pump	P	P	P	P	Accept
7. Expend/Therm Storage - PH_4Cl	P	M	M	P	Accept*
8. Vehicle Umbilical	P	P	P	P	Accept
9. Cryogenic H_2	F	F	F	P	Reject

P = Pass
F = Fail
M = Marginal
* = Marginal Acceptance

TABLE 3-4. GO/NO GO EVALUATION - CO_2 CONTROL (SHUTTLE)

Concept	Criteria				Remarks
	Performance	Crew Acceptability	Safety	Availability	
1. LiOH	P	P	P	P	Accept
2. Li_2O_2	P	P	P	P	Accept
3. Purge Flow - VEH Umbilical	P	P	P	P	Accept
4. Demand Flow - VEH Umbilical	P	P	P	P	Accept
5. Metallic Oxides	P	P	P	P	Accept
6. Solid Amine	P	P	P	P	Accept
7. Metal Hydroxides	P	P	P	P	Accept

P = Pass
F = Fail
M = Marginal
* = Marginal Acceptance

TABLE 3-5. GO/NO GO EVALUATION - O_2 SUPPLY (SHUTTLE)

Concept	Criteria				Remarks
	Performance	Crew Acceptability	Safety	Availability	
1. Gaseous Storage	P	P	P	P	Accept
2. $NaClO_3$ Candle	P	P	P	P	Accept
3. Vehicle Umbilical	P	P	P	P	Accept
4. H_2O_2 (with Maneuvering Only)	M	M	M	P	Accept*

P = Pass
F = Fail
M = Marginal
* = Marginal Acceptance

TABLE 3-6. GO/NO GO EVALUATION - THERMAL CONTROL (EMERGENCY SYSTEMS)

Concept	Criteria				Remarks
	Performance	Crew Acceptability	Safety	Availability	
1. H_2O Boiler	P	P	P	P	Accept
2. H_2O Sublimator	P	P	P	P	Accept
3. Thermal Storage - PH_4Cl	P	M	M	P	Accept*
4. Thermal Storage - Eutectic Salt	P	P	P	P	Accept
5. Thermal Storage - Ice	P	P	P	P	Accept
6. Redundant Primary System	P	P	P	P	Accept
7. Vehicle Umbilical	P	P	P	P	Accept

P = Pass
F = Fail
M = Marginal
* = Marginal Acceptance

TABLE 3-7. GO/NO GO EVALUATION - CO_2 CONTROL (EMERGENCY SYSTEMS)

Concept	Criteria				Remarks
	Performance	Crew Acceptability	Safety	Availability	
1. ZnO	P	P	P	P	Accept
2. MgO	P	P	P	P	Accept
3. Li_2O_2	P	P	P	P	Accept
4. $Mg(OH)_2$	P	P	P	P	Accept
5. $Zn(OH)_2$	P	P	P	P	Accept
6. LiOH	P	P	P	P	Accept
7. KO_2	P	P	P	P	Accept
8. Solid Amine	P	P	P	P	Accept
9. Vehicle Umbilical	P	P	P	P	Accept
10. Purge Flow	P	P	P	P	Accept

P = Pass
F = Fail
M = Marginal
* = Marginal Acceptance

TABLE 3-8. GO/NO GO EVALUATION - O_2 SUPPLY (EMERGENCY SYSTEMS)

Concept	Criteria				Remarks
	Performance	Crew Acceptability	Safety	Availability	
1. Gaseous Storage	P	P	P	P	Accept
2. $NaClO_3$ Candle	P	P	P	P	Accept
3. Li_2O_2	P	P	P	P	Accept
4. KO_2	P	P	P	P	Accept
5. Vehicle Umbilical	P	P	P	P	Accept

P = Pass
F = Fail
M = Marginal
* Marginal Acceptance

4.0 PARAMETRIC ANALYSIS

4.0 PARAMETRIC ANALYSES

A detailed parametric analysis of each candidate subsystem concept which passed the go/no go evaluation was conducted to evaluate vehicle weight and volume versus total EVA mission time and AEPS volume and weight versus EVA mission duration.

4.1 Phase One Effort

This section consists of the parametric analyses conducted during phase one of the AEPS Study.

Section 4.1.1 presents the thermal/humidity control parametric analysis which evaluate the effect upon the candidate concepts of varying average thermal load from 1500-2500 BTU/hr, peak thermal load from 3000-5000 BTU/hr, and AEPS power penalty from 100-200 watt-hrs/lb. The CO_2 control/O_2 supply subsystem parametric analysis is presented in Section 4.1.2 and evaluated the effect upon the candidate concepts of varying metabolic load (CO_2 production rate) from 400-2500 BTU/hr while maintaining the suit inlet CO_2 partial pressure below 4 mm Hg. Although not shown in the schematics, a 6000 psi oxygen supply subsystem is included in the parametric data.

The parametric analyses are based upon an extrapolation of in-house and published test data and a projection of both state-of-the-art and design/development improvements achievable by the 1980's. In addition to presentation of the parametric data, this section contains a schematic and functional description of each candidate concept.

4.1.1 THERMAL/HUMIDITY CONTROL

CONCEPT 1 - WATER BOILER

The water boiler is an expendable thermal control concept that utilizes the heat of vaporization of water to provide direct cooling of the Liquid Cooling Garment (LCG) loop and vent loop. The wick-fed water boiler also acts as the storage vessel for the expendable water. The expendable water boiling temperature is controlled by a Back Pressure Valve (BPV), which is either a temperature sensing or pressure sensing flow control valve. Crewman comfort is achieved automatically by the Temperature Control Valve (TCV). Separated water is fed into the water boiler, thus providing additional cooling capacity. A relief valve furnishes protection against overpressurization due to storage temperature fluctuations. Recharge is simply accomplished utilizing the fill valve.

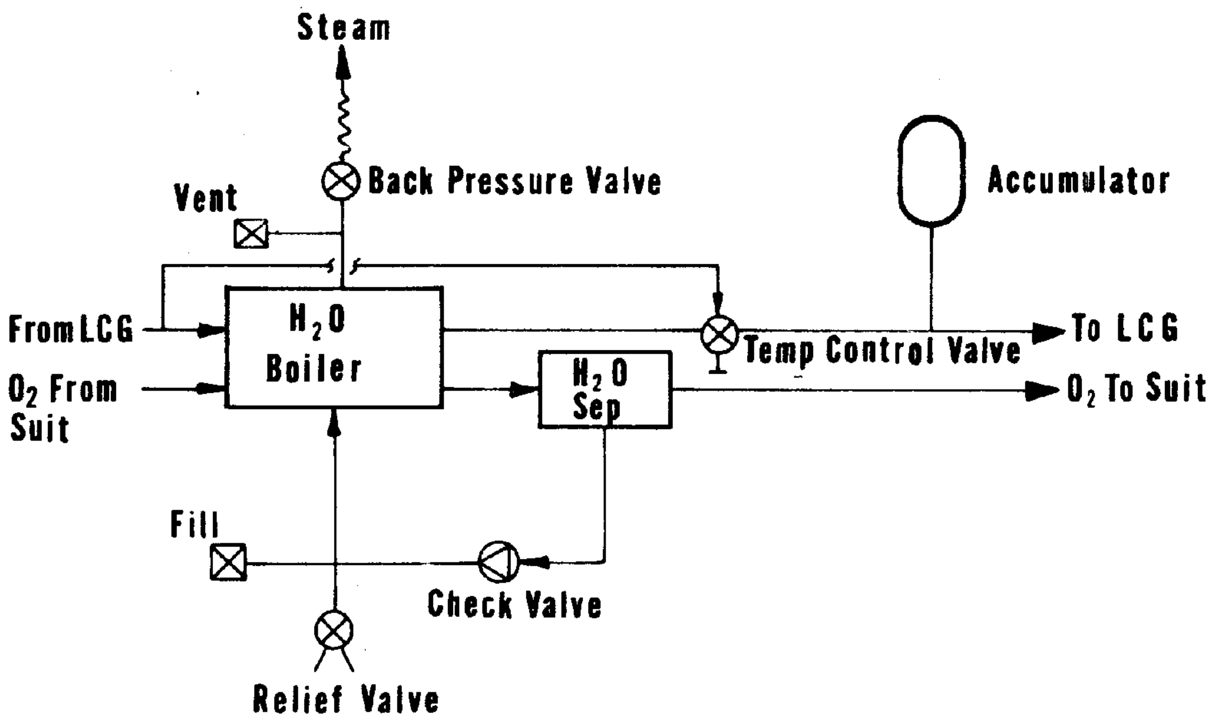
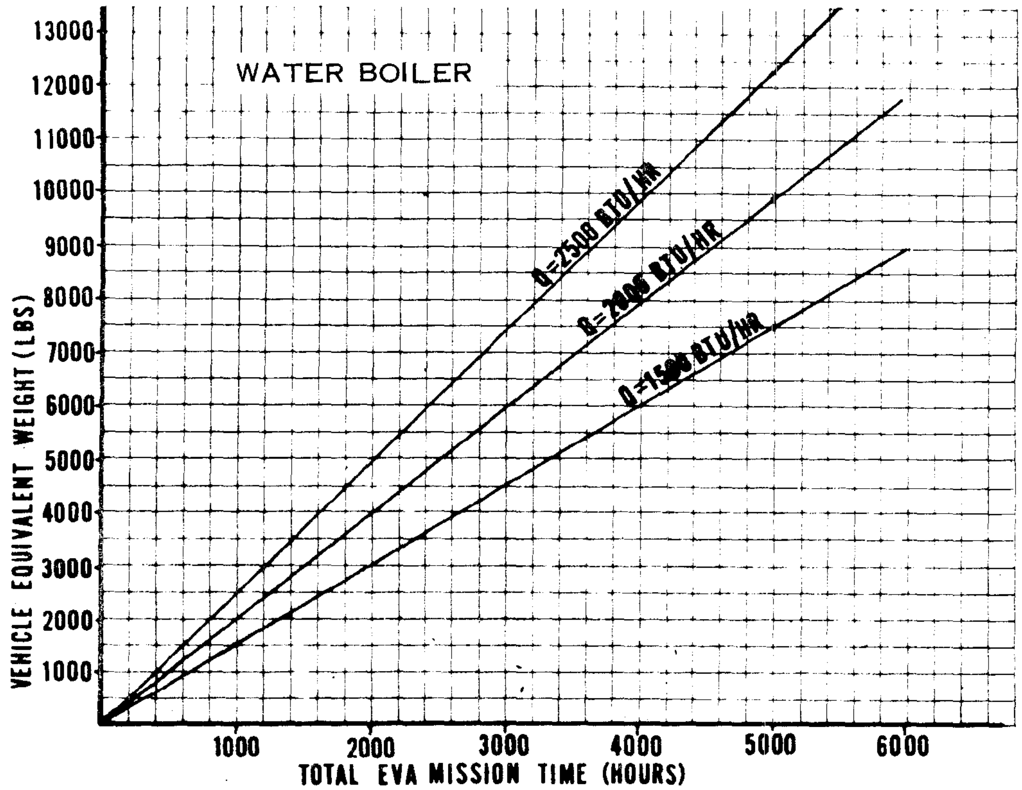
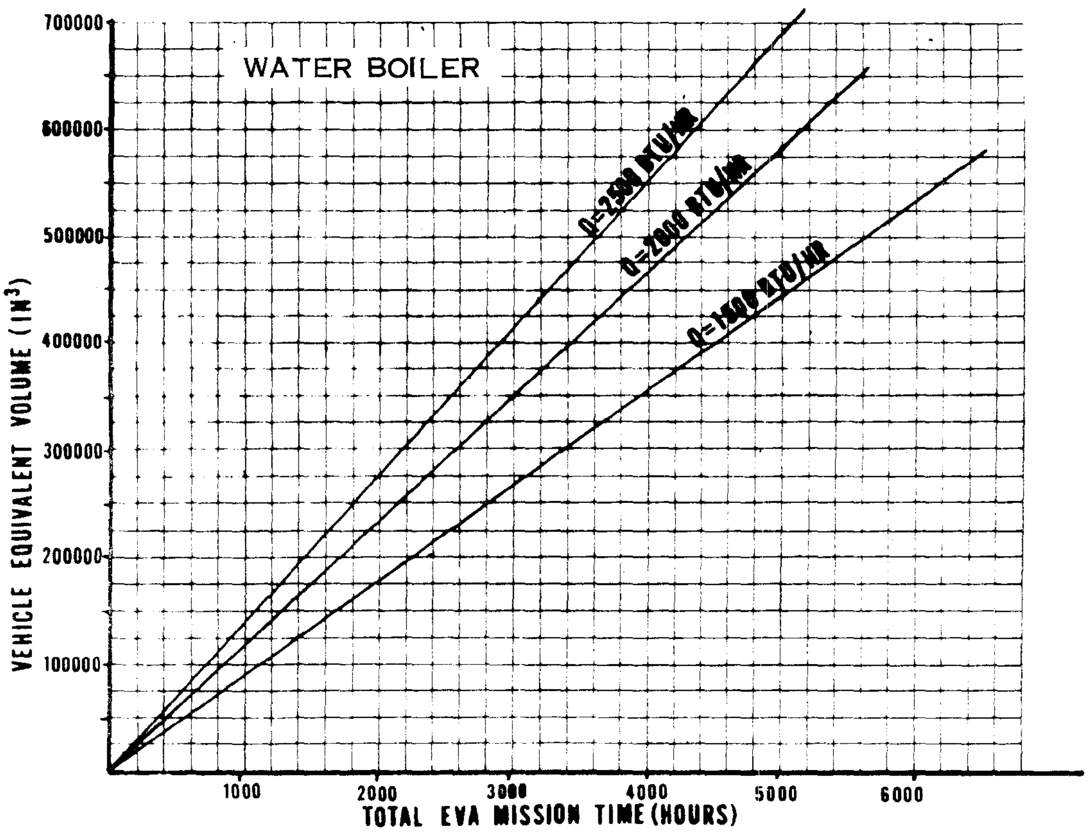


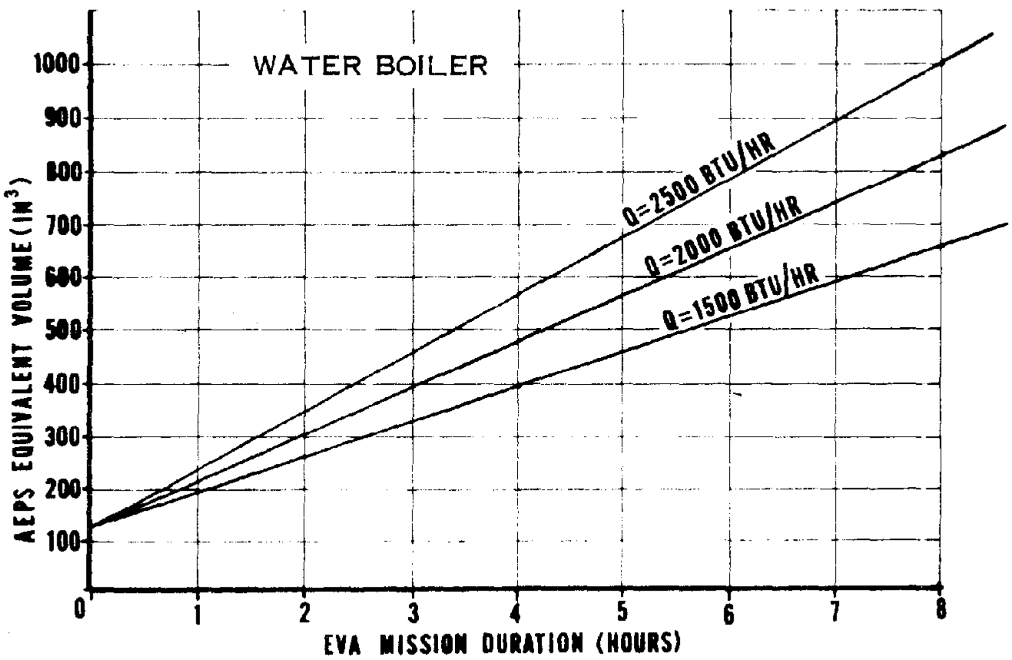
FIGURE 4–1. WATER BOILER

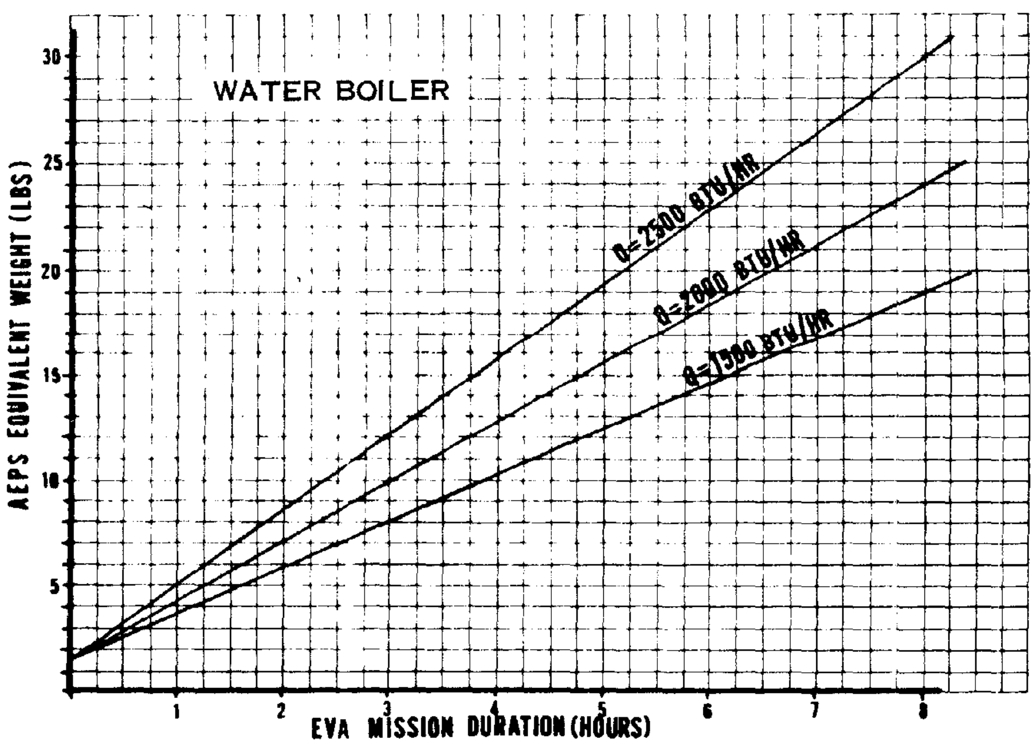


WATER BOILER
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
VEHICLE EQUIVALENT WEIGHT (LBS)
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
1000
2000
3000
4000
5000
6000
TOTAL EVA MISSION TIME (HOURS)



WATER BOILER
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
VEHICLE EQUIVALENT VOLUME (IN^3)
700000
600000
500000
400000
300000
200000
100000
1000
2000
3000
4000
5000
6000
TOTAL EVA MISSION TIME (HOURS)


WATER BOILER
AEPS EQUIVALENT VOLUME (IN³)
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR


WATER BOILER
AEPS EQUIVALENT WEIGHT (LBS)
30
25
20
15
10
5
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR

CONCEPT 2 - WATER SUBLIMATOR

The water sublimator is an expendable thermal control concept that utilizes the heat of sublimation to provide direct cooling of the LCG and vent loops. In order to minimize AEPS expendables, the Apollo EMU sublimator concept was modified to permit utilization of the separated water to provide additional cooling capacity. The sublimator is a porous media heat exchanger wherein the downstream side of the porous media is subjected to hard vacuum and the upstream side is supplied with expendable water. Upon startup, the sudden drop in pressure across the porous media freezes the expendable water within the porous media. The addition of heat from the LCG and vent loops sublimes the ice on the vacuum end of the porous media and thus the thermal load is rejected to space. The sublimator is supplied expendable water from a pressure-fed bladder tank which is pressurized by the vent loop. A flow limiting orifice prevents breakthrough of the sublimator on startup.

A motor driven rotary water separator positively expels separated water from the vent loop downstream of the sublimator to the feed side of the water reservoir. A check valve insures positive separated water expulsion and a gas trap (may not be required) prevents sublimator breakthrough from gas bubbles. Check and relief valves are added for safety and a fill connector and dump valve permits recharge. The TCV provides LCG temperature control. This concept will not work on Mars because of the atmospheric pressure on Mars.

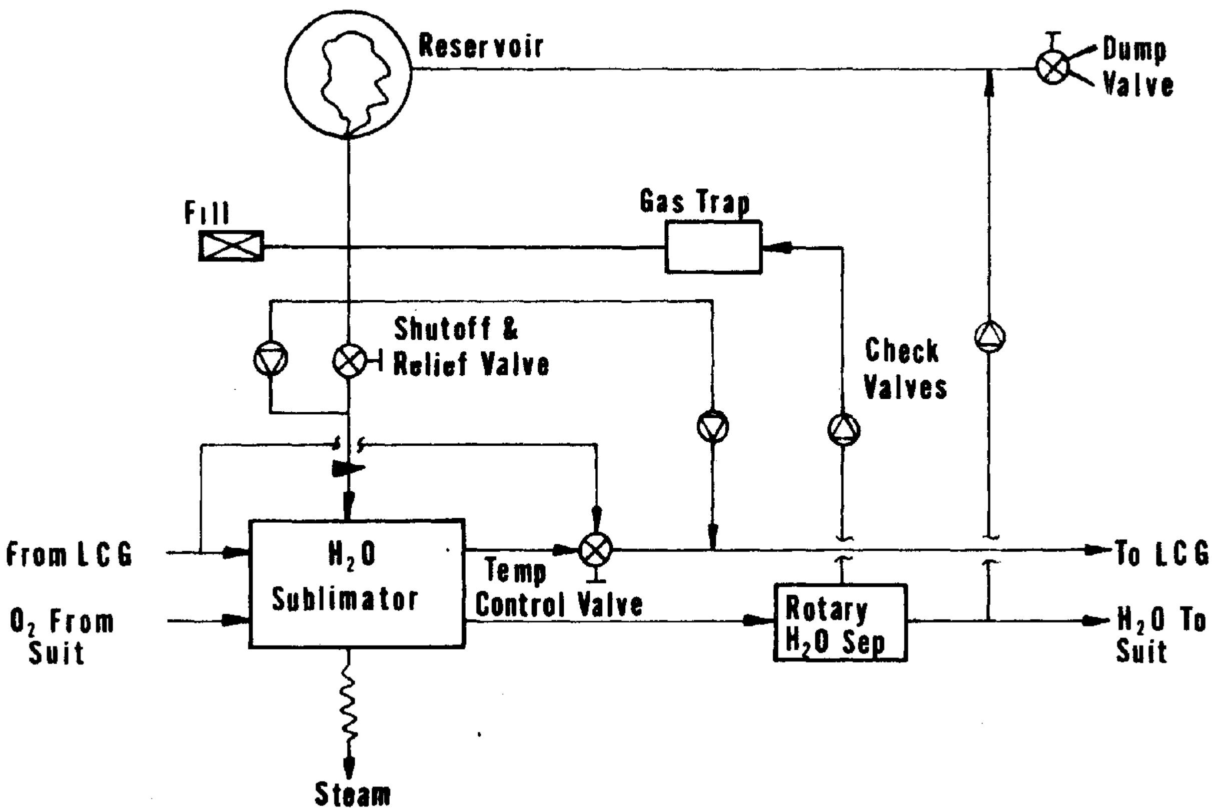
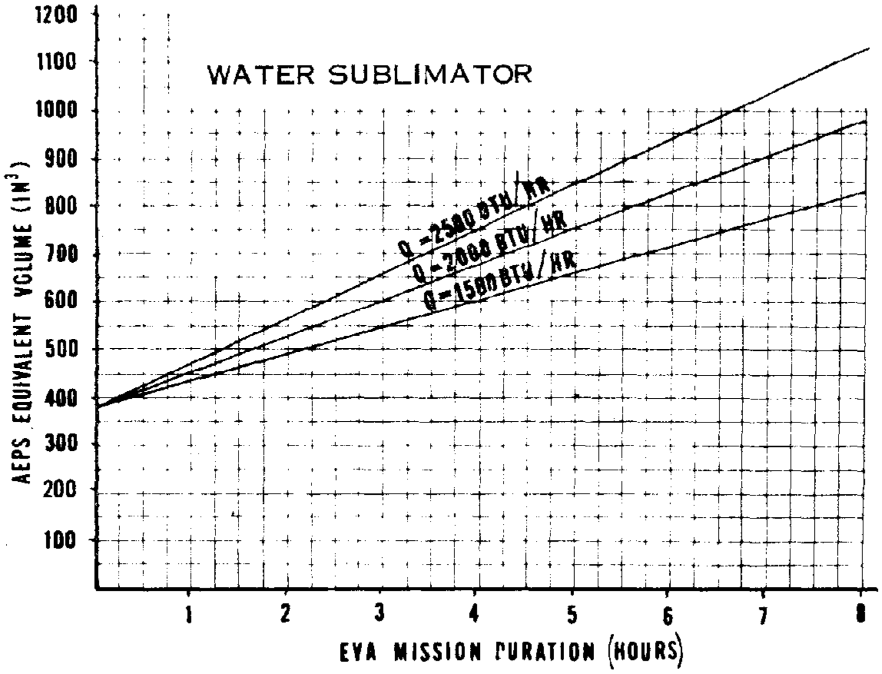
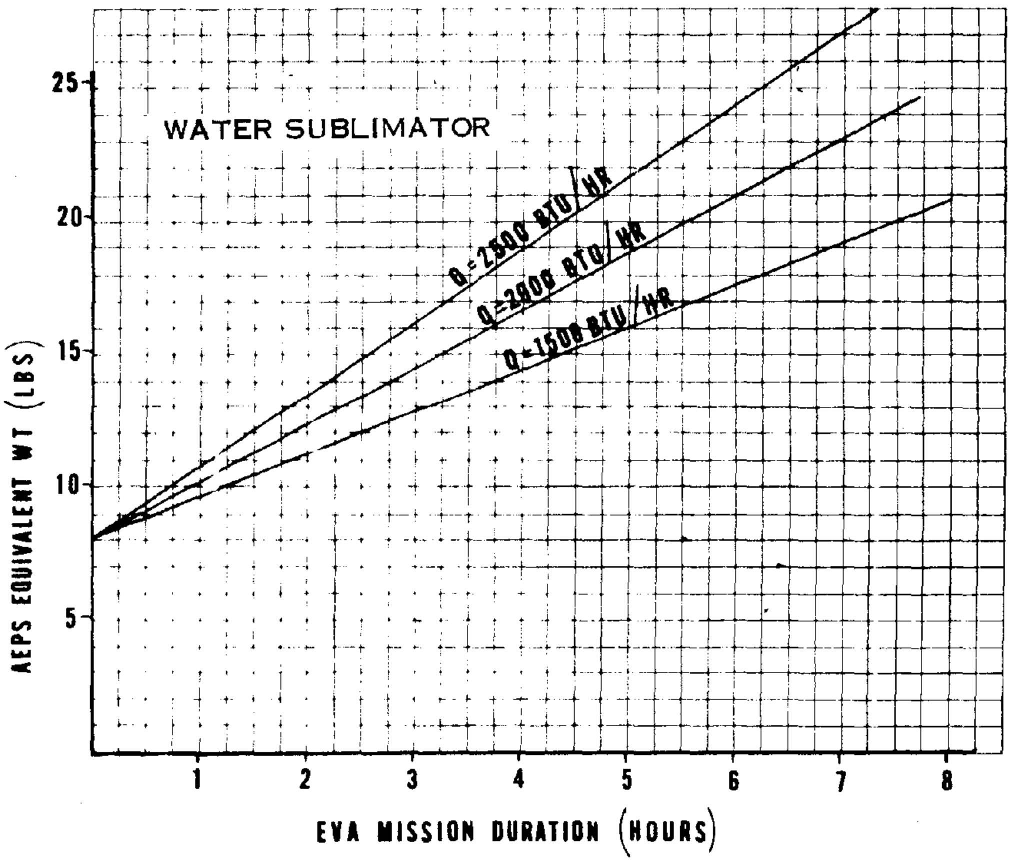


FIGURE 4–2. WATER SUBLIMATOR


WATER SUBLIMATOR
AEPS EQUIVALENT VOLUME (IN³)
1200
1100
1000
900
800
700
600
500
400
300
200
100
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)


WATER SUBLIMATOR
AEPS EQUIVALENT WT (LBS)
25
20
15
10
5
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)

CONCEPT 3 - PLATE FIN FLASH EVAPORATOR

The plate fin flash evaporator concept is schematically the same as the water sublimator concept except that the sublimator and expendable water shutoff and relief valve are replaced with a plate fin flash evaporator and a solenoid actuated flow control valve. The valve is varied via an electronic controller as a function of LCG evaporator outlet temperature. Spray bars create a high velocity spray aimed at the heat transfer surfaces internal to the evaporator. The evaporator is configured with the aid of baffles to produce good impingement of the spray on the heat transfer surface where flash vaporization occurs. Vaporization of the spray at the heat transfer surface is the mechanism by which heat is transferred from the vent and LCG loops. Proper control of the inlet flow as a function of LCG outlet temperature eliminates the need for a back pressure valve or wicking media as is required in the water boiler. Temperature control is, however, more complex and water carryover is of much more concern than in the water boiler or water sublimator concepts.

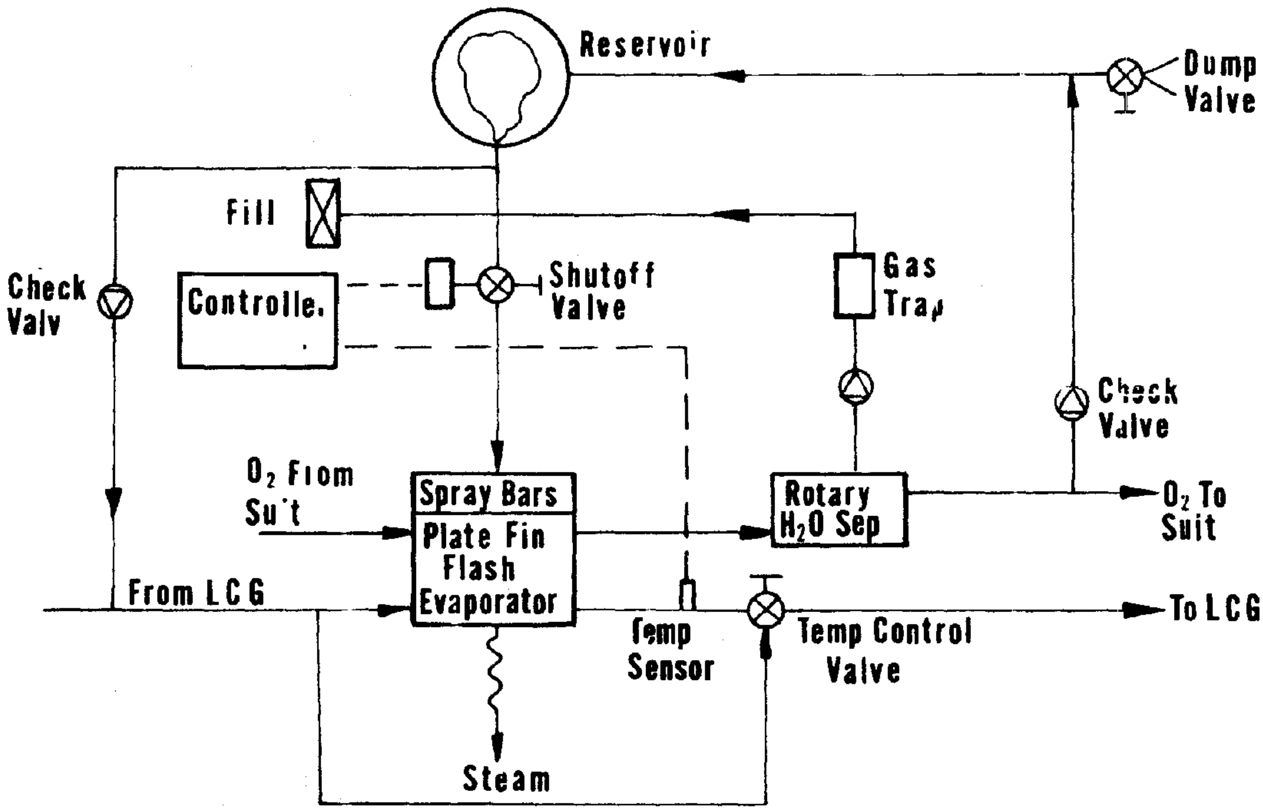


FIGURE 4–3. PLATE FIN FLASH EVAPORATOR

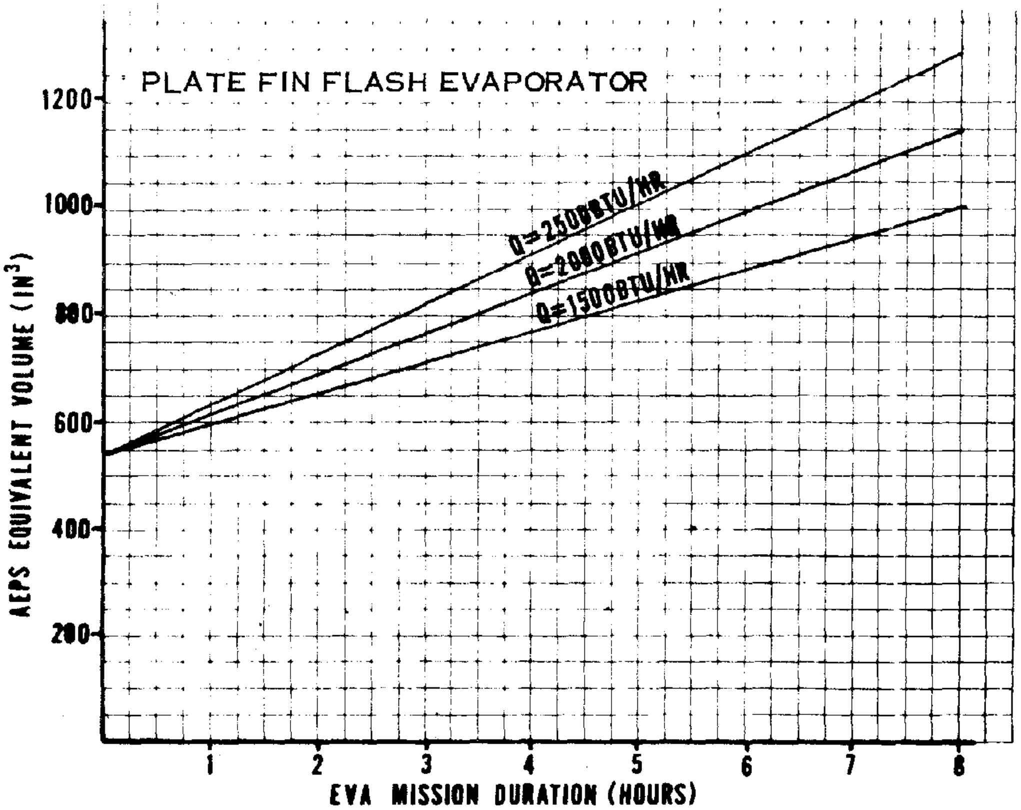
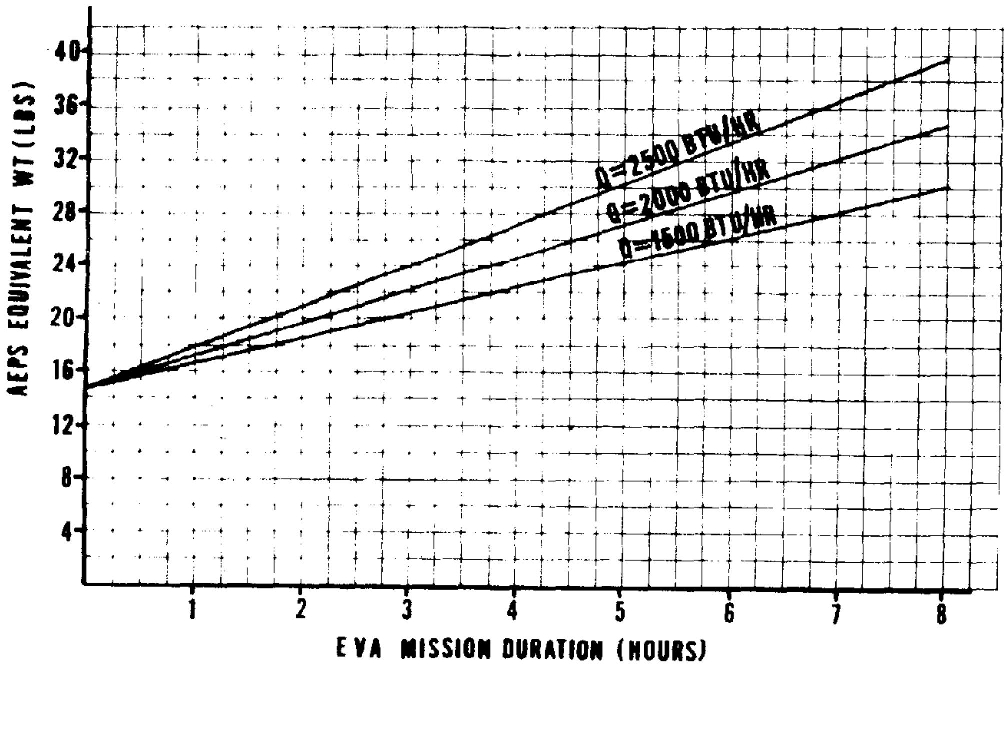


PLATE FIN FLASH EVAPORATOR
Q=2500BTU/HR
Q=2000BTU/HR
Q=1500BTU/HR
AEPS EQUIVALENT VOLUME (IN^3)
1200
1000
800
600
400
200
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)


Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
AEPS EQUIVALENT WT (LBS)
40
36
32
28
24
20
16
12
8
4
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)

CONCEPT 4 - ROTARY FLASH EVAPORATOR

A chief concern of the plate fin flash evaporator is excessive water carryover of water injected into the evaporator due to either not being able to impinge on a heat transfer surface before exiting or vaporization occurring away from the heat transfer surface. The rotary flash evaporator addresses itself to this problem by creating a centrifugal force field on the injected water by injecting it into a rotating drum, the outer surface of which is the heat transfer surface. The mechanism of heat transfer in this concept may be either flash evaporation or nucleate boiling. An electrical motor has been chosen as the evaporator driving mechanism to ensure start-up and to overcome seal friction. It appears that the seal and bearing design, as well as the inlet flow control function, are the areas which require the major development effort.

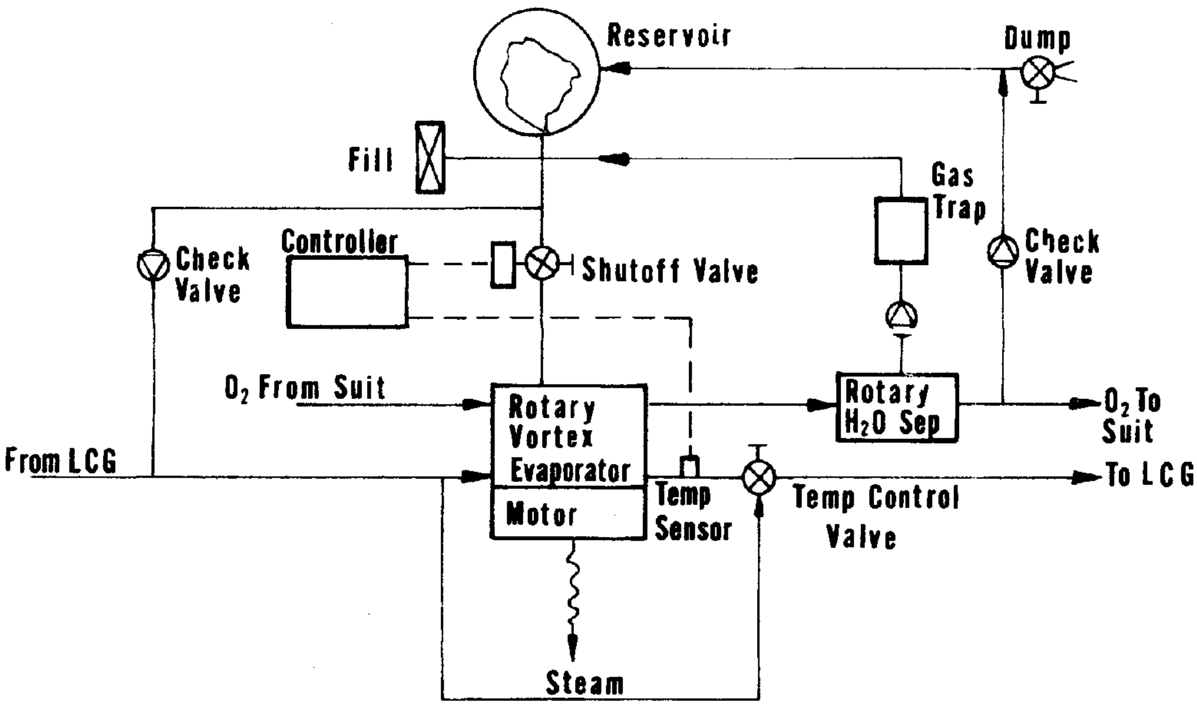
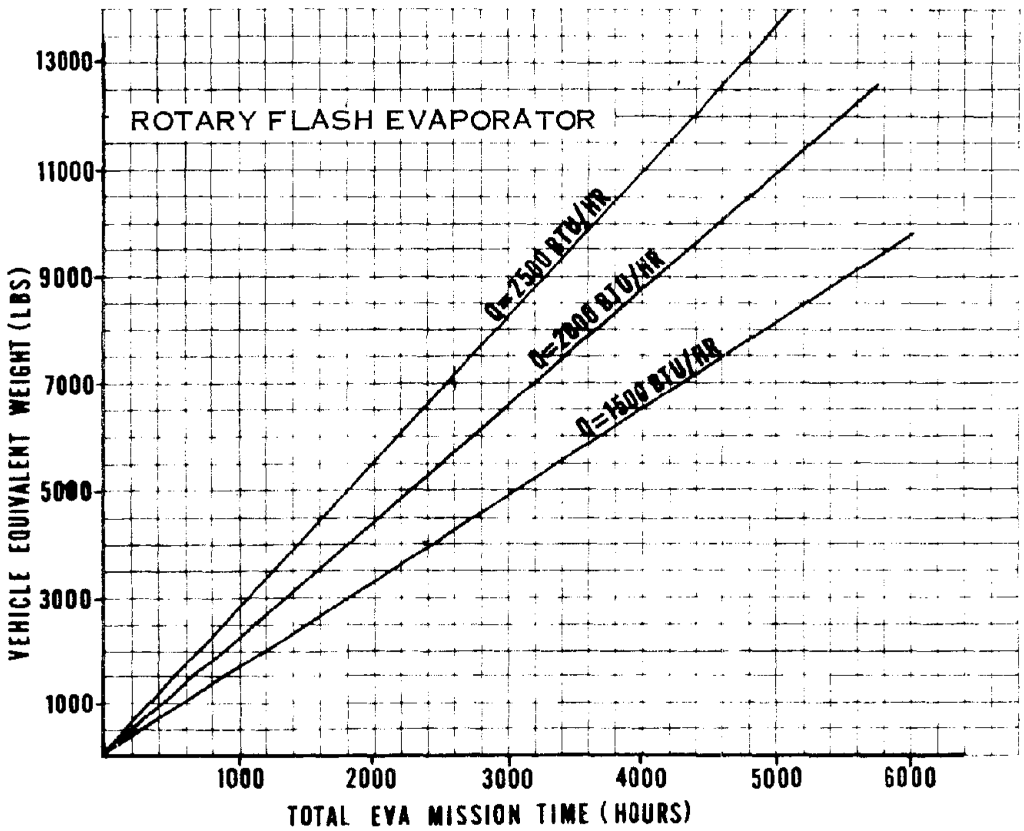
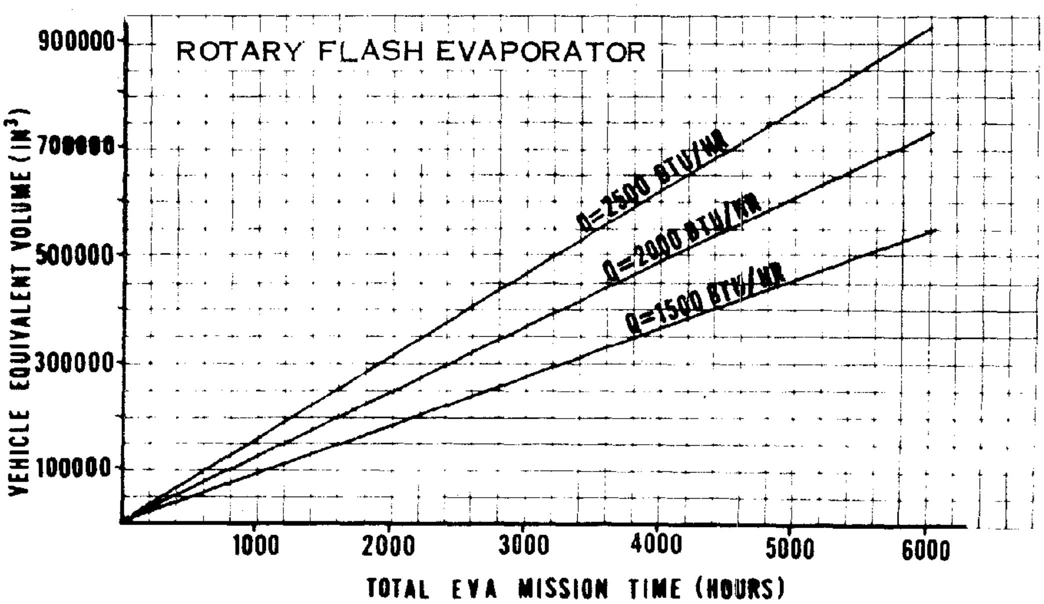
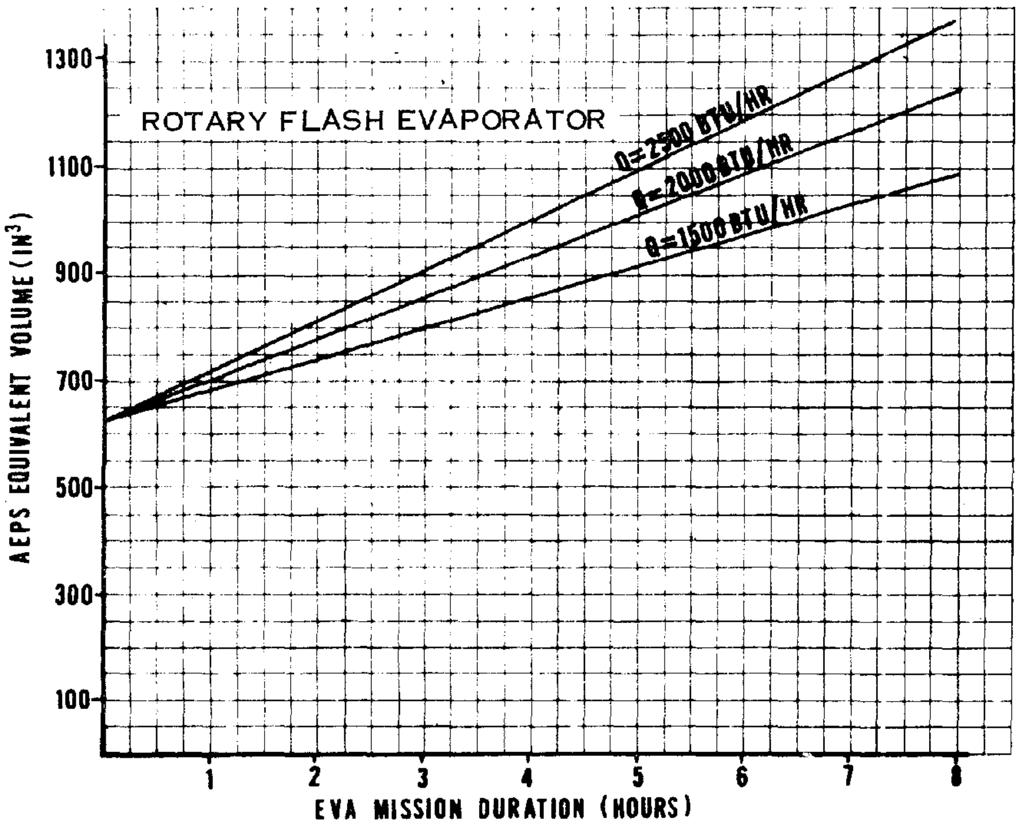
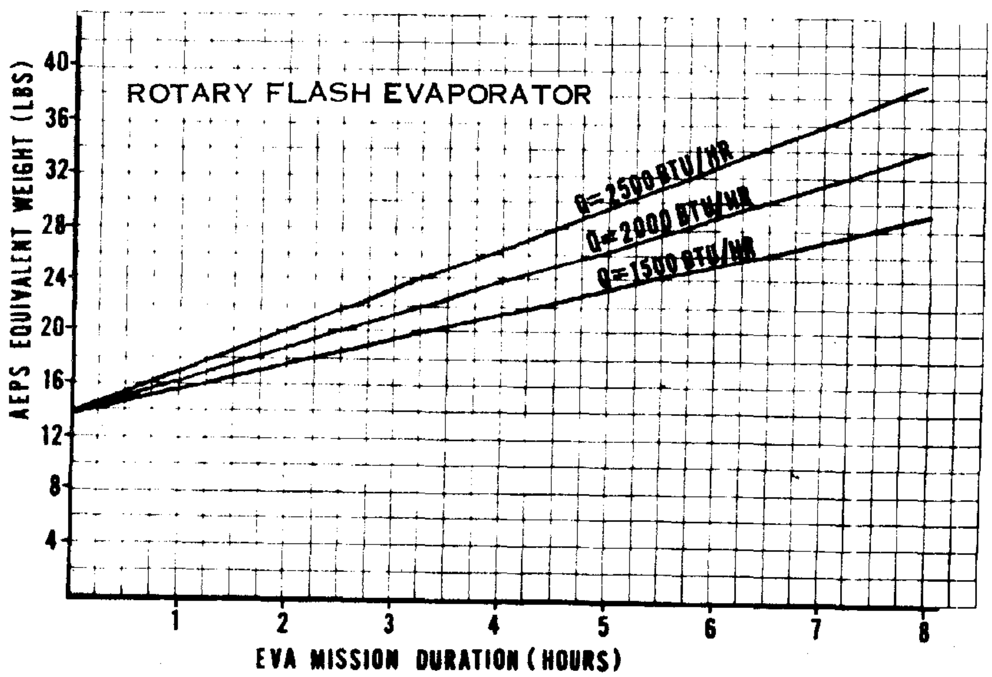


FIGURE 4–4. ROTARY FLASH EVAPORATOR


ROTARY FLASH EVAPORATOR
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HOURS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
13000
11000
9000
7000
5000
3000
1000
1000
2000
3000
4000
5000
6000


ROTARY FLASH EVAPORATOR
VEHICLE EQUIVALENT VOLUME (IN³)
TOTAL EVA MISSION TIME (HOURS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
900000
700000
500000
300000
100000
1000
2000
3000
4000
5000
6000


ROTARY FLASH EVAPORATOR
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HOURS)


ROTARY FLASH EVAPORATOR
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HOURS)

CONCEPT 5 - VAPOR DIFFUSION THROUGH SUIT PRESSURE VALVES

This expendable water concept, currently being developed by McDonnell-Douglas for NASA-MSC, consists of cooling patches which lay next to the skin on non-articulated portions of the body, an expendable water reservoir, temperature, pressure, and flow control valves, and a suit garment. Body moisture is wicked into the adsorbent conductive mesh. This system's advantages are that it eliminates the LCG and pump, the humidity control subsystem, and it integrates the expendable water reservoir and water boiler into the suit. The cooling patches act as water boilers and consist of an outer and inner impermeable membrane, a wicking layer, a vapor cavity, a suit garment, and a pressure regulating valve. Fill and drain connectors are provided for recharge. However, temperature control for this concept is complex and crewman mobility may be seriously impaired by the resultant configuration.

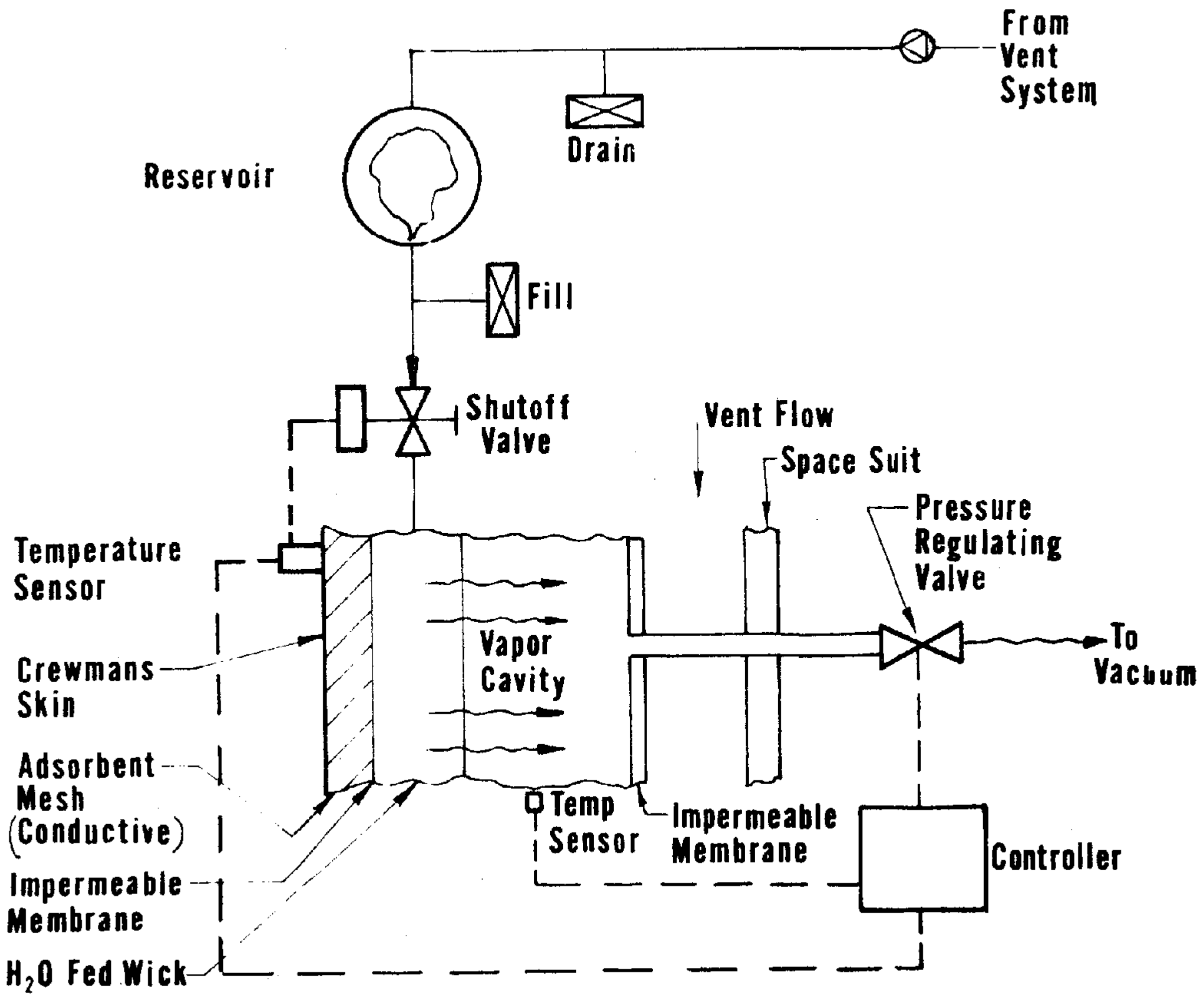
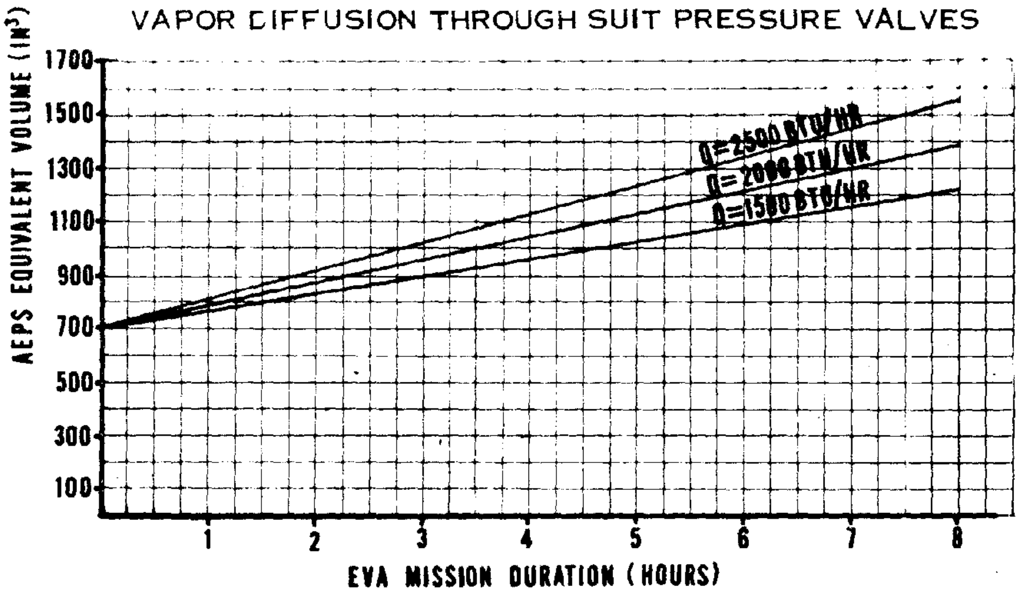
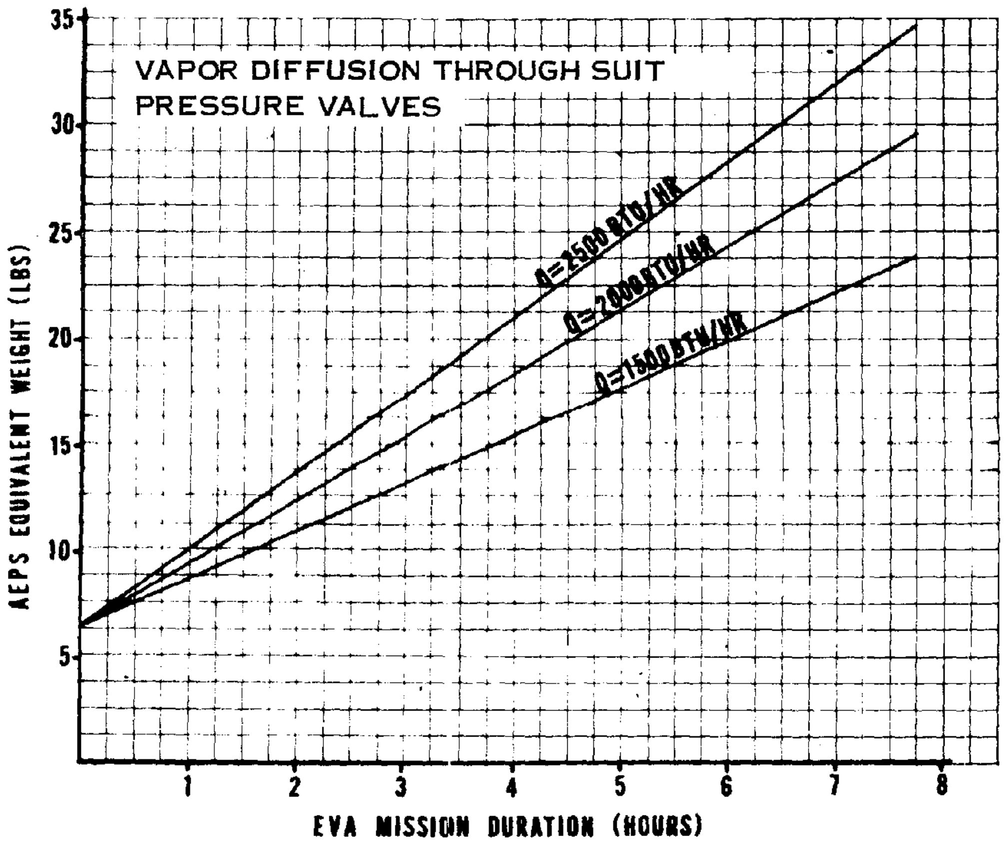


FIGURE 4–5. VAPOR DIFFUSION THROUGH SUIT PRESSURE VALVES


VAPOR DIFFUSION THROUGH SUIT PRESSURE VALVES
AEPS EQUIVALENT VOLUME (IN³)
1700
1500
1300
1100
900
700
500
300
100
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)


VAPOR DIFFUSION THROUGH SUIT PRESSURE VALVES
AEPS EQUIVALENT WEIGHT (LBS)
35
30
25
20
15
10
5
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)

CONCEPT 6 - DIRECT RADIATIVE COOLING USING LCG

Direct radiative cooling is a non-expendable concept that dissipates the LCG thermal load via radiation to deep space and indirectly cools the vent loop by a condensing heat exchanger in the LCG loop, downstream of the radiator. Humidity control is attained by removal of condensed moisture by the water separator which transfers it to a holding tank. The automatic TCV provides LCG temperature control.

Since radiator sizing is based on the maximum thermal load, prevention of overcooling of the crewman and/or freezeup of the LCG at low load conditions is required. This may be achieved by variable area, conductance and/or emissivity control techniques in the radiator design. Sizing is affected by the solar constant, time of lunar or Martian day, the ground view factor, and the radiator values of emissivity and absorbtivity. The assumption is made that planned maintenance can successfully retain radiator surface properties. Radiator sizing is based on subsolar conditions with a ground view factor of zero. This concept, because of its size, is suitable only to a "cart-type" configuration and is, therefore, eliminated from consideration for the Space Station application.

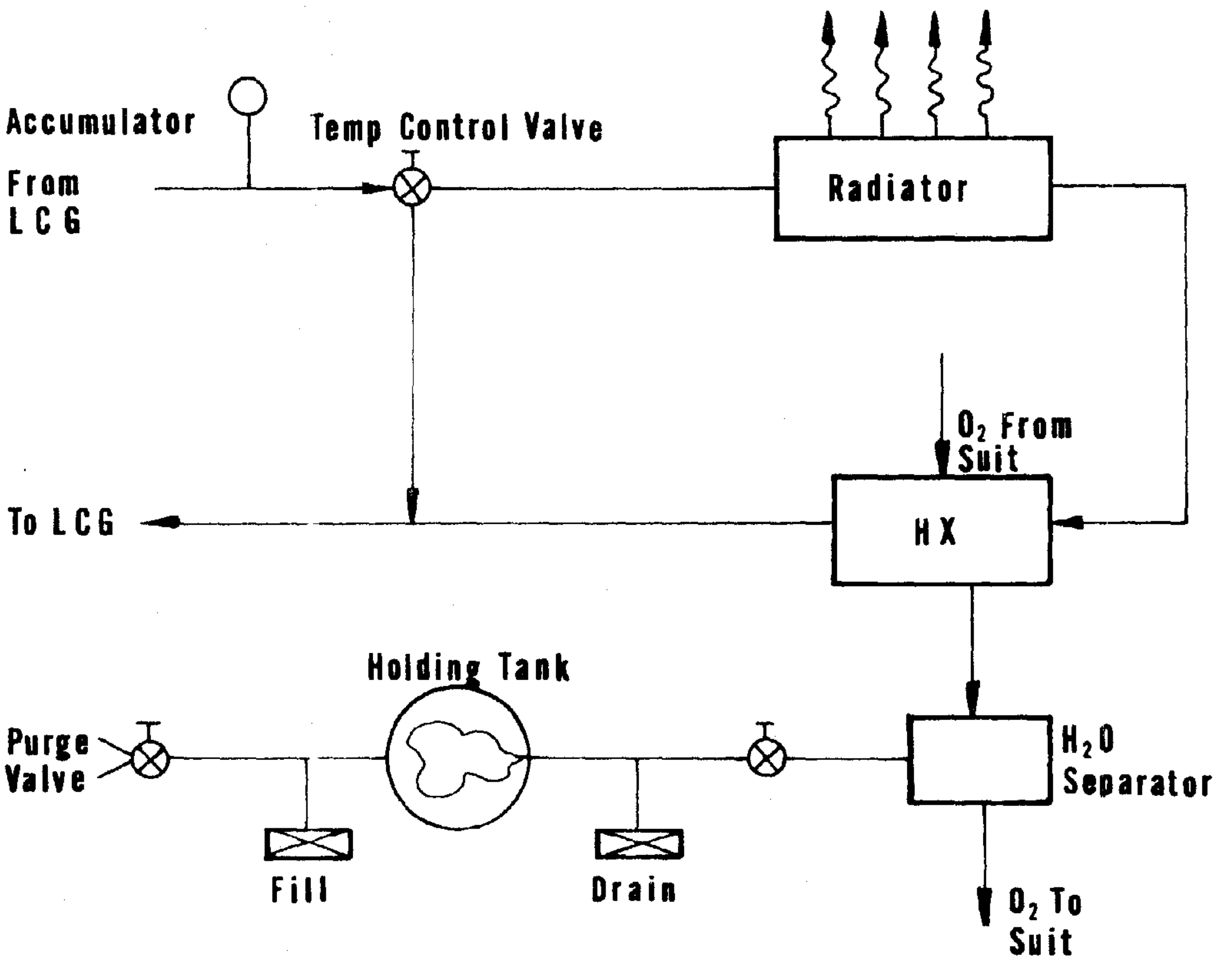
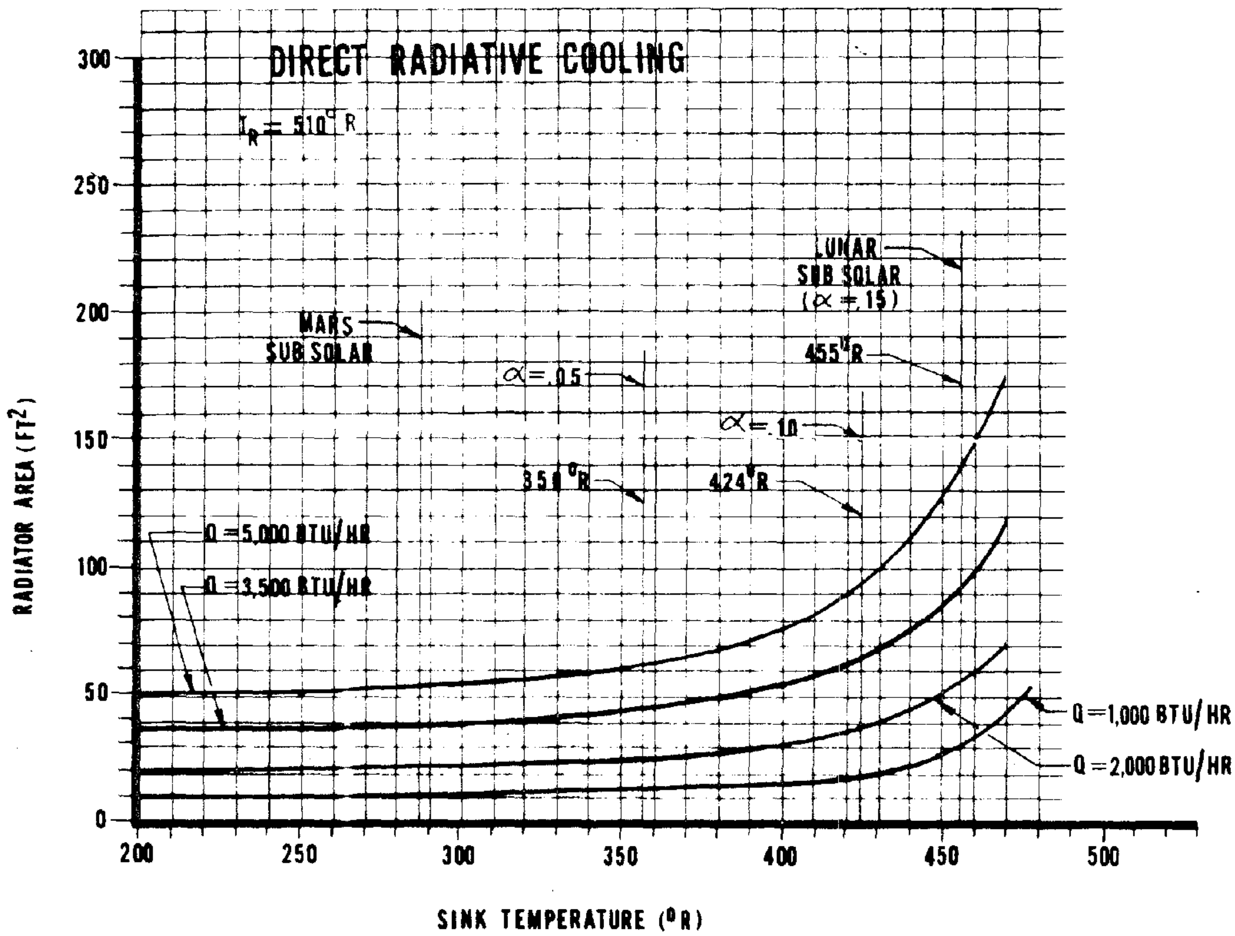
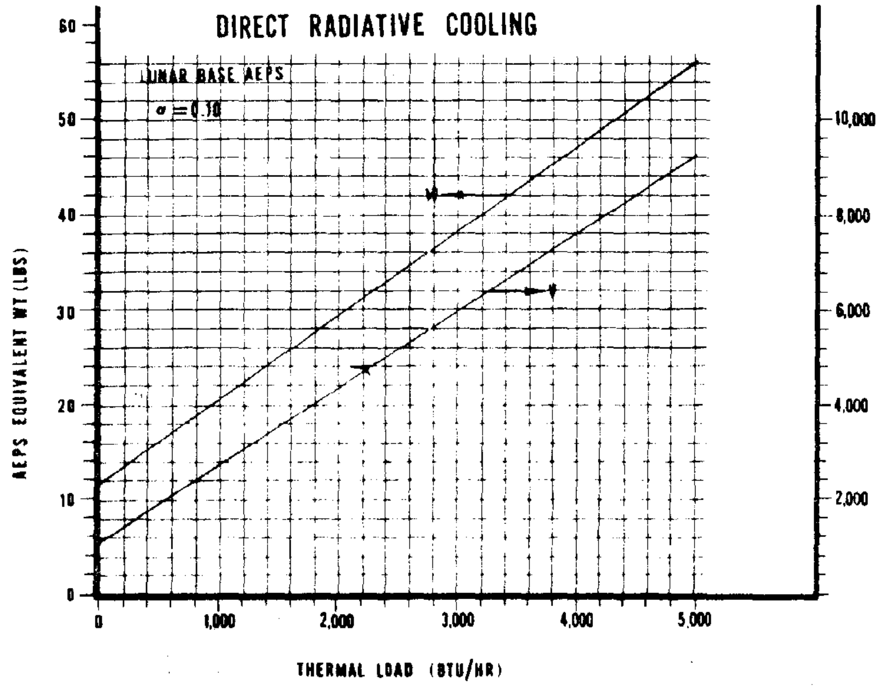


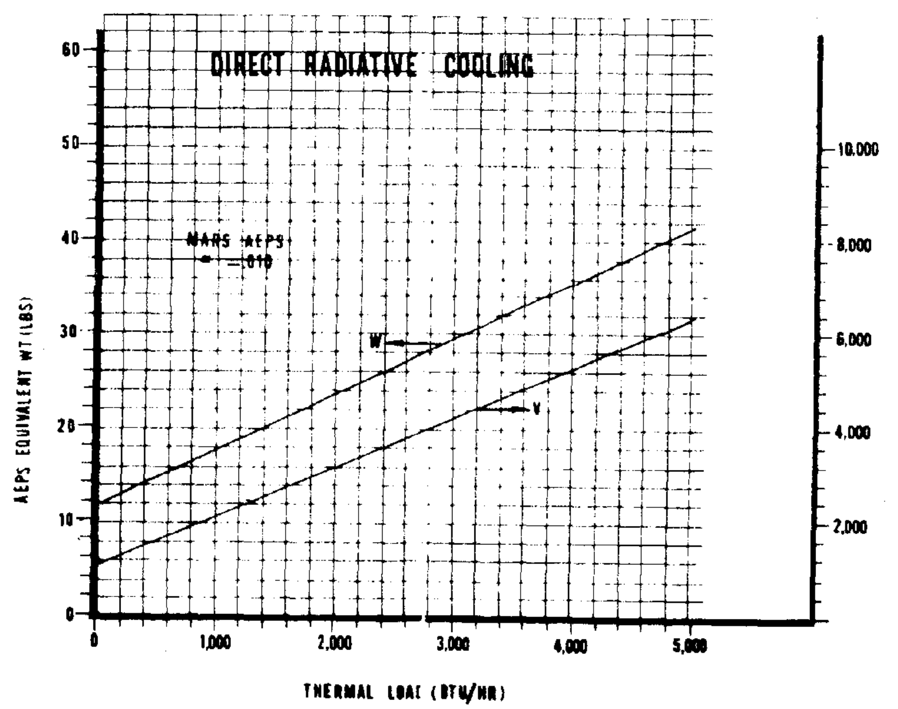
FIGURE 4—6. DIRECT RADIATIVE COOLING USING LCG



DIRECT RADIATIVE COOLING
T_R = 510° R
MARS SUB SOLAR
LUNAR SUB SOLAR (α = .15)
455°R
α = .05
α = .10
358°R
424°R
Q = 5,000 BTU/HR
Q = 3,500 BTU/HR
Q = 1,000 BTU/HR
Q = 2,000 BTU/HR
RADIATOR AREA (FT²)
SINK TEMPERATURE (°R)
0
50
100
150
200
250
300
200
250
300
350
400
450
500



DIRECT RADIATIVE COOLING
LUNAR BASE AEPS
$\alpha = 0.10$
W
V
AEPS EQUIVALENT WT (LBS)
AEPS EQUIVALENT VOLUME (IN³)
THERMAL LOAD (BTU/HR)
0
10
20
30
40
50
60
1,000
2,000
3,000
4,000
5,000
2,000
4,000
6,000
8,000
10,000



DIRECT RADIATIVE COOLING
MARS AEPS
W
V
AEPS EQUIVALENT WT (LBS)
AEPS EQUIVALENT VOLUME (IN³)
THERMAL LOAD (BTU/HR)
0
10
20
30
40
50
60
1,000
2,000
3,000
4,000
5,000
2,000
4,000
6,000
8,000
10,000

CONCEPT 7 - FREON REFRIGERATION CYCLE

In order to minimize radiator surface area, a heat pump utilizing a vapor compression cycle was incorporated into the previous concept. This vapor compression cycle utilizes a Freon as a coolant and consists of a radiator, expansion valve, evaporator and compressor. The vent and LCG loops add heat to the refrigeration loop in the evaporator, thus vaporizing the coolant. The coolant is in turn pumped by a compressor up to the radiator saturation pressure. Heat is rejected to deep space by radiation with the coolant giving up its heat by condensing. The pressure and temperature of the condensed coolant is reduced across the expansion valve to the evaporator conditions where the coolant is revaporized to complete the cycle. The automatic TCV provides LCG temperature control. The water separator and holding tank remove and store condensed vent loop moisture downstream of the evaporator. Since the radiator sizing is based on the maximum thermal load, a variable speed compressor and variable orifice are necessary to prevent overcooling of the crewman and/or freezeup of the LCG at low load conditions.

It is assumed planned maintenance retains radiator surface properties. Sizing is based on subsolar conditions with a ground view factor of zero. This concept, because of its size, is suitable only to a "cart-type" configuration and is, therefore, eliminated from consideration on the Space Station application.

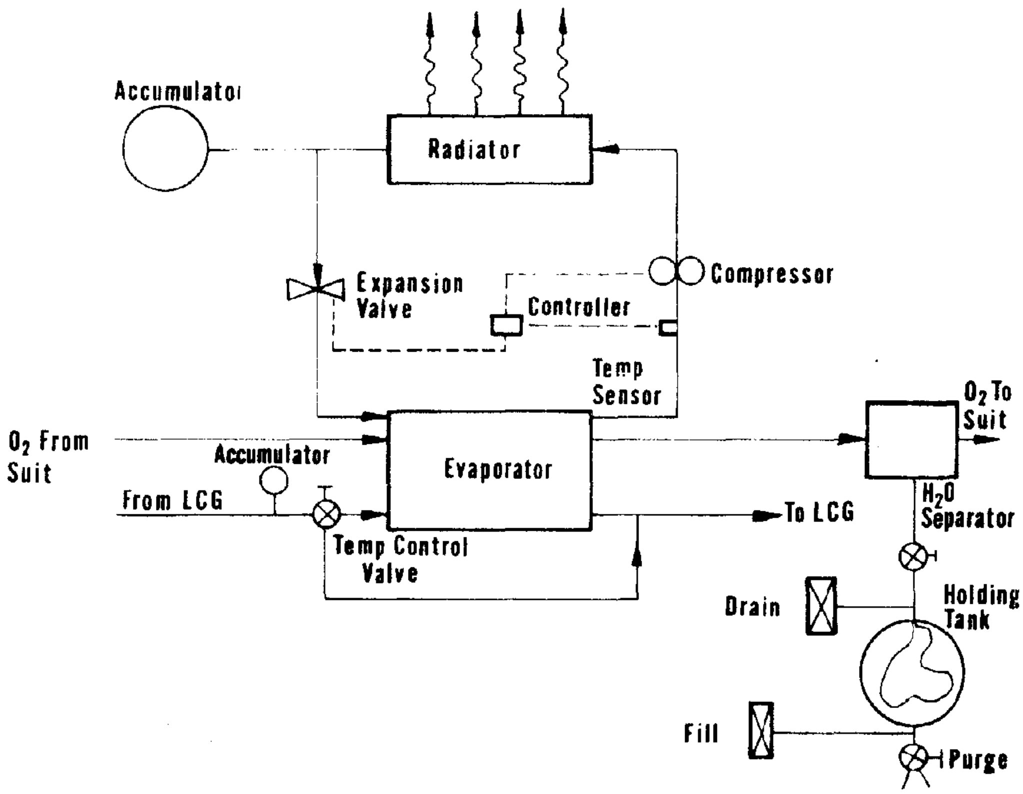
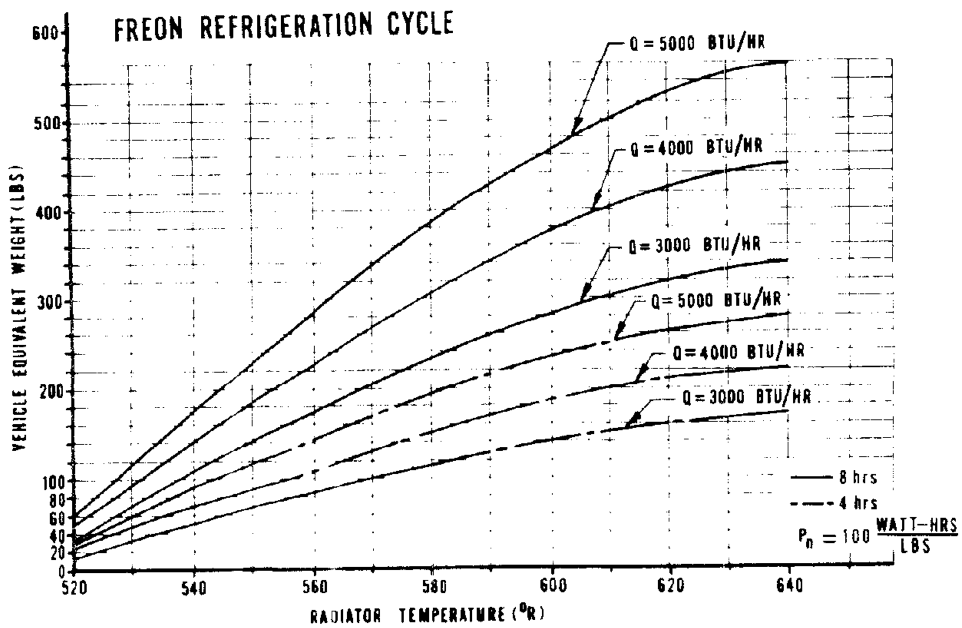
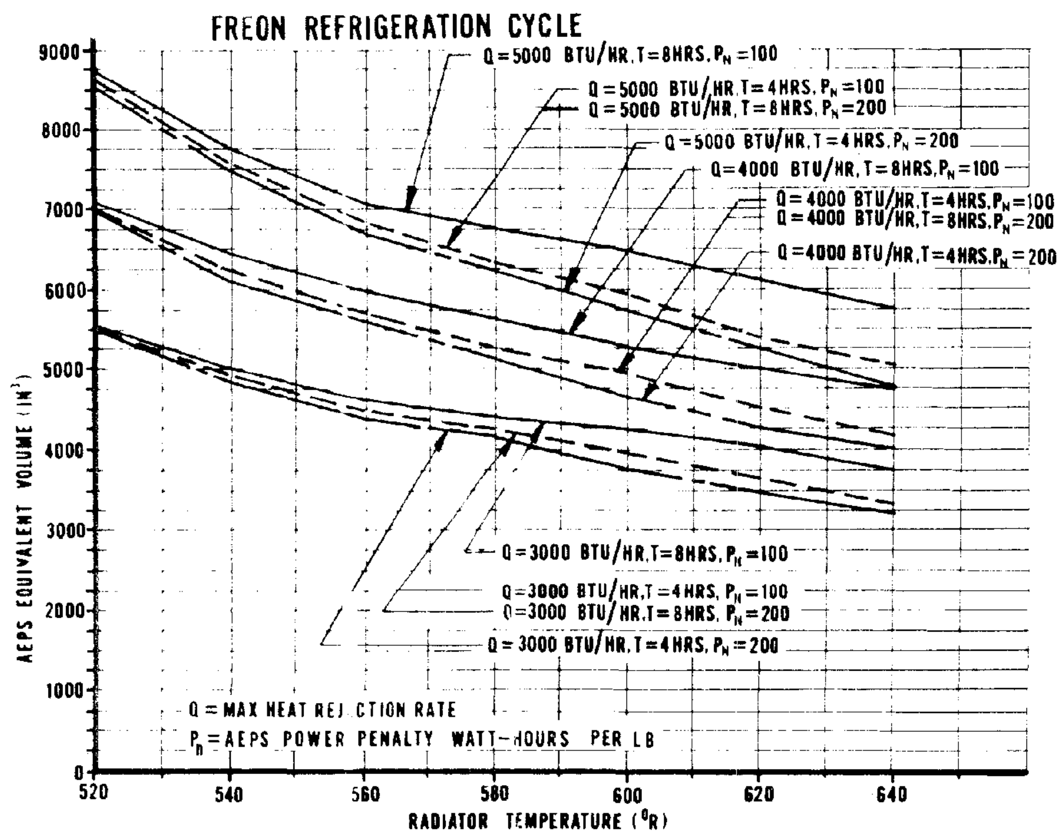


FIGURE 4–7. FREON REFRIGERATION CYCLE

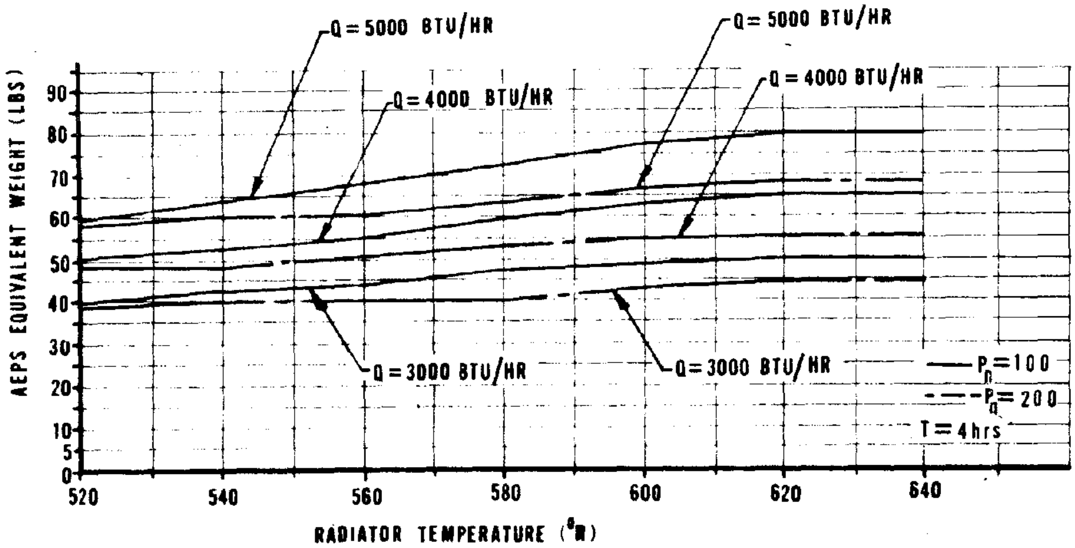


FREON REFRIGERATION CYCLE
Q = 5000 BTU/HR
Q = 4000 BTU/HR
Q = 3000 BTU/HR
Q = 5000 BTU/HR
Q = 4000 BTU/HR
Q = 3000 BTU/HR
8 hrs
4 hrs
$P_n = 100 \frac{\text{WATT-HRS}}{\text{LBS}}$
VEHICLE EQUIVALENT WEIGHT (LBS)
RADIATOR TEMPERATURE (°R)

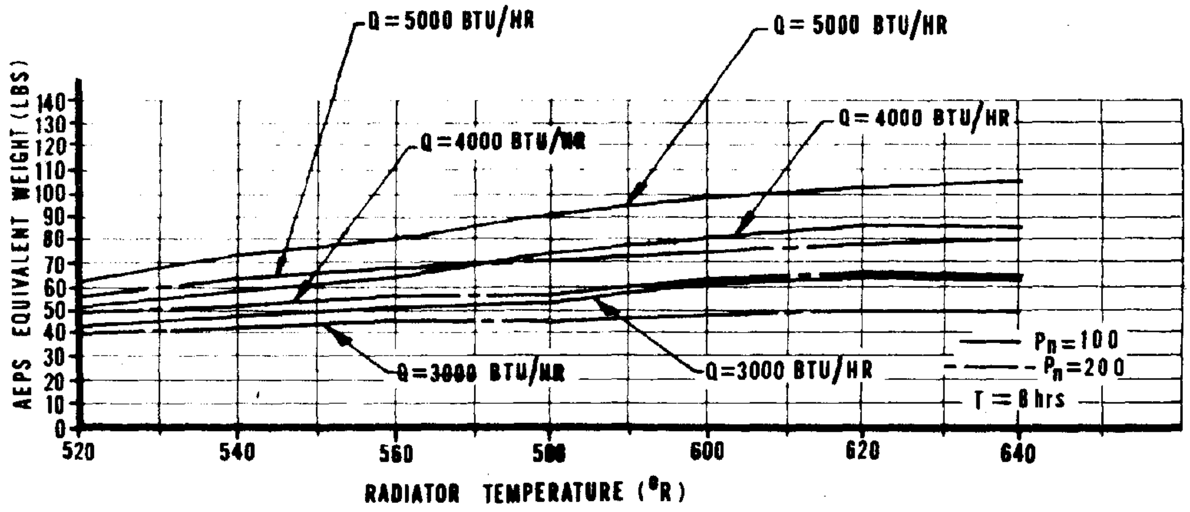


FREON REFRIGERATION CYCLE
Q = 5000 BTU/HR, T = 8HRS, P_N = 100
Q = 5000 BTU/HR, T = 4HRS, P_N = 100
Q = 5000 BTU/HR, T = 8HRS, P_N = 200
Q = 5000 BTU/HR, T = 4 HRS, P_N = 200
Q = 4000 BTU/HR, T = 8HRS, P_N = 100
Q = 4000 BTU/HR, T = 4HRS, P_N = 100
Q = 4000 BTU/HR, T = 8HRS, P_N = 200
Q = 4000 BTU/HR, T = 4HRS, P_N = 200
Q = 3000 BTU/HR, T = 8HRS, P_N = 100
Q = 3000 BTU/HR, T = 4 HRS, P_N = 100
Q = 3000 BTU/HR, T = 8 HRS, P_N = 200
Q = 3000 BTU/HR, T = 4 HRS, P_N = 200
Q = MAX HEAT REJ CTION RATE
P_n = AEPS POWER PENALTY WATT-HOURS PER LB
AEPS EQUIVALENT VOLUME (IN³)
RADIATOR TEMPERATURE (°R)

FREON REFRIGERATION CYCLE



FREON REFRIGERATION CYCLE



CONCEPT 8 - DIRECT COOLING VIA H_2O ADSORPTION/RADIATION

A combination water adsorption/radiation concept utilizes the heat of vaporization of water in the evaporator to provide direct cooling of the LCG and vent loops and the heat of adsorption to reject the system heat load via the radiator. The evaporator is fed water by a pressurized bladder tank. Water flow rate is controlled by a solenoid valve and controller as a function of LCG evaporator outlet temperature. The evaporator effluent water vapor is adsorbed by lithium bromide in the adsorber, the heat of adsorption being dissipated by radiation to deep space. LCG temperature control is achieved by the automatic TCV.

Radiator sizing is based on the heat of reaction per pound of water vapor, the maximum allowable vapor pressure and temperature the chemical can support, and the maximum water feed rate. Lithium bromide was chosen over calcium chloride (a close second), lithium chloride, and sodium selenide since its initial heat of reaction is lowest and thus requires the smallest radiator. It is important that the hydrated lithium bromide crystal does not go into solution with water: therefore, adequate design margin on chemical sizing is necessary as well as insuring good water vapor flow distribution in the adsorber. The water is reclaimed in the vehicle by desorbing the chemical by an electrical heater and recondensing the effluent water vapor.

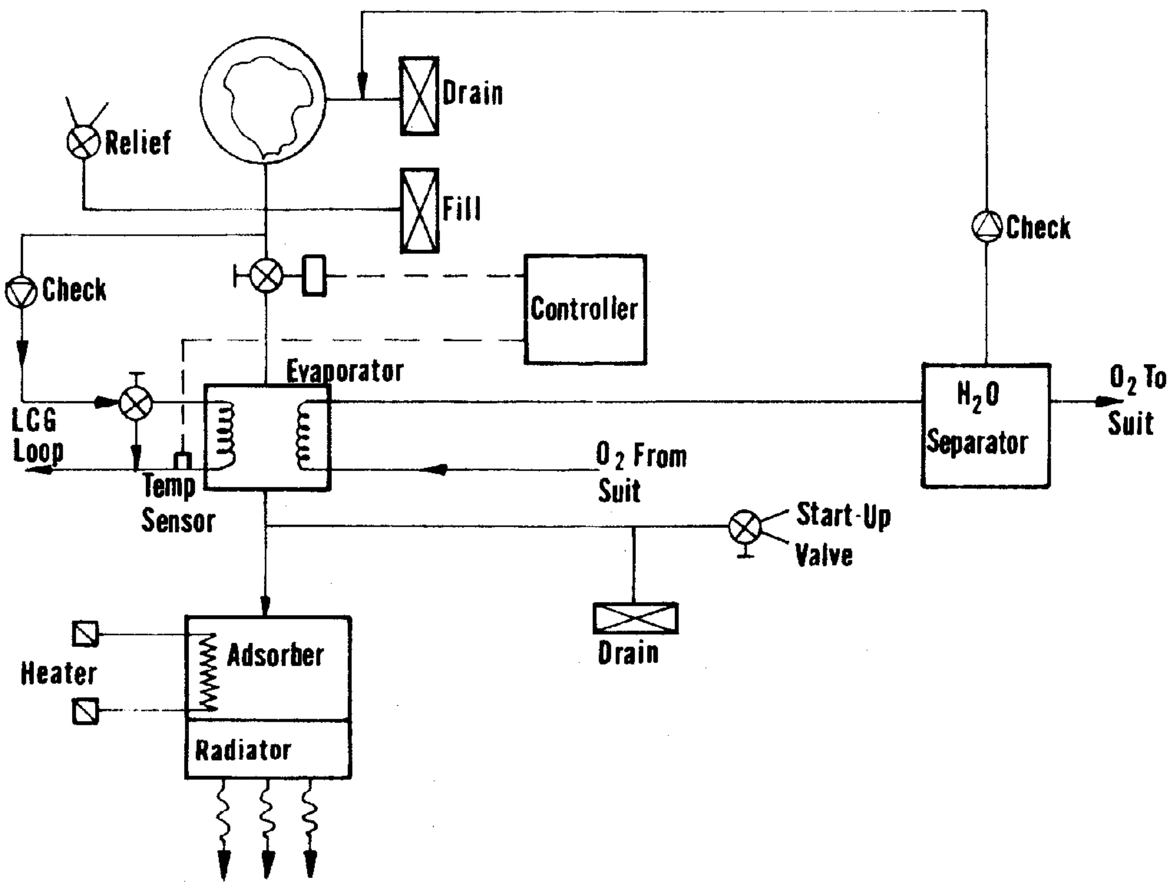
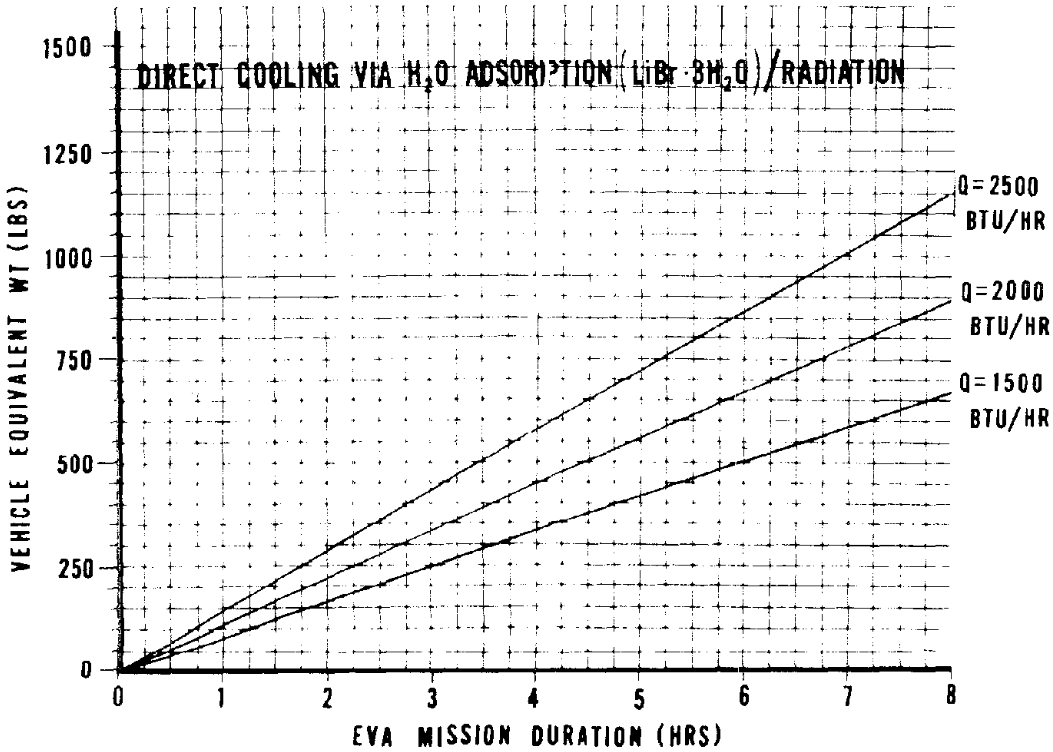
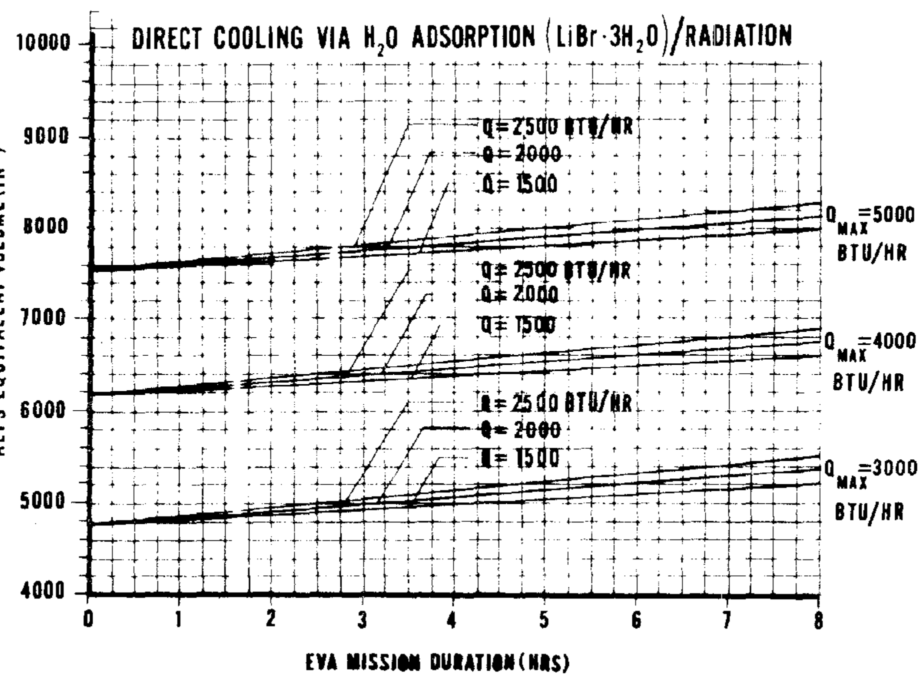
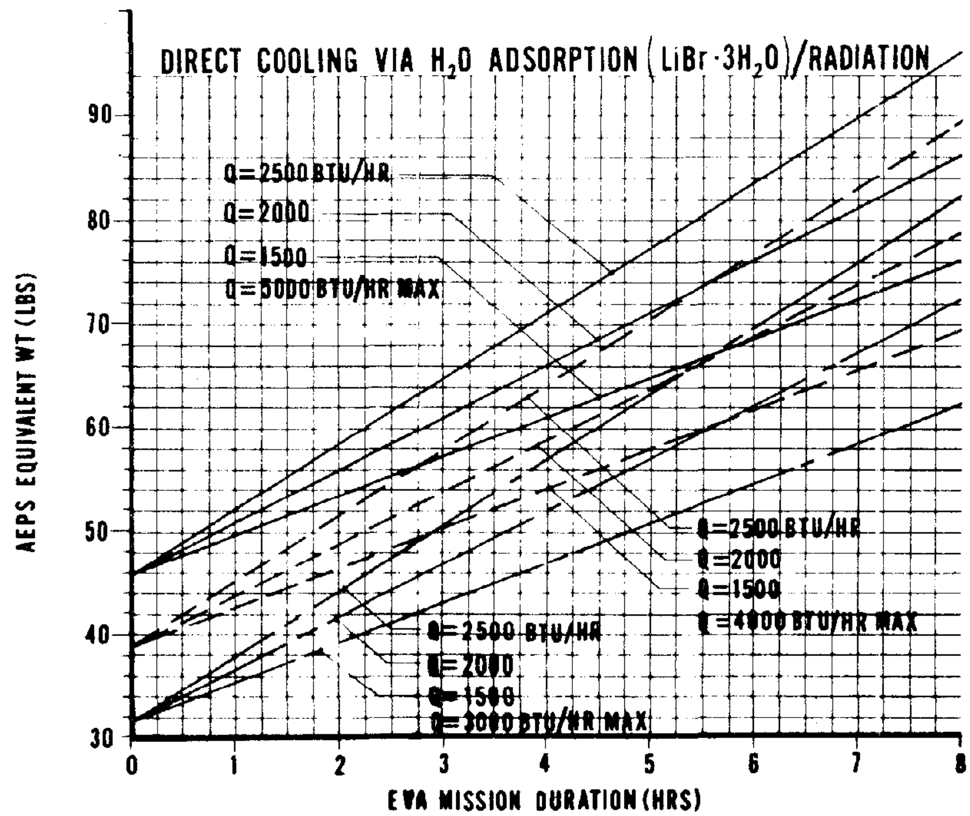
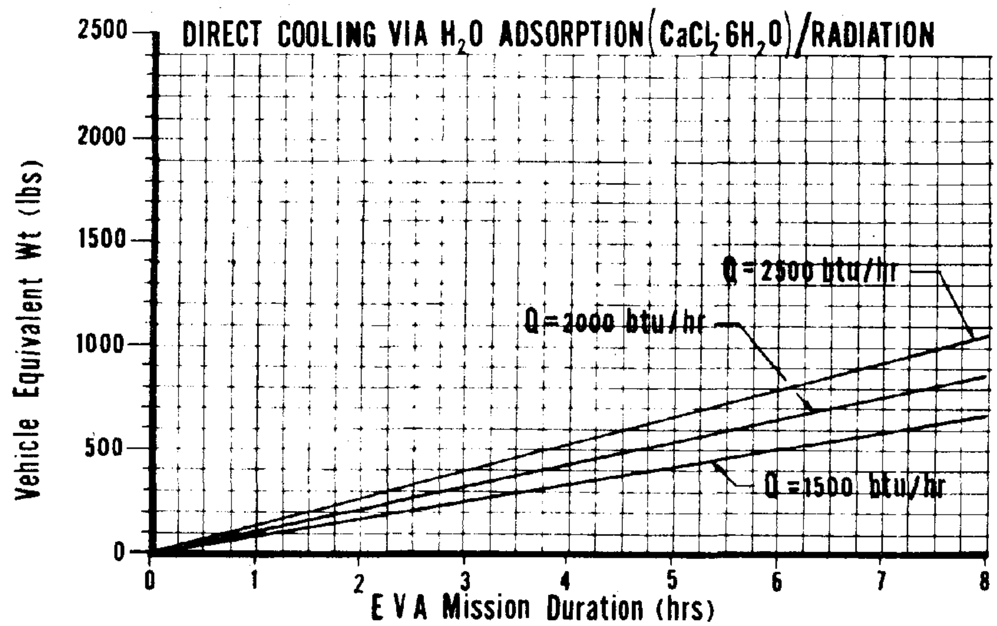


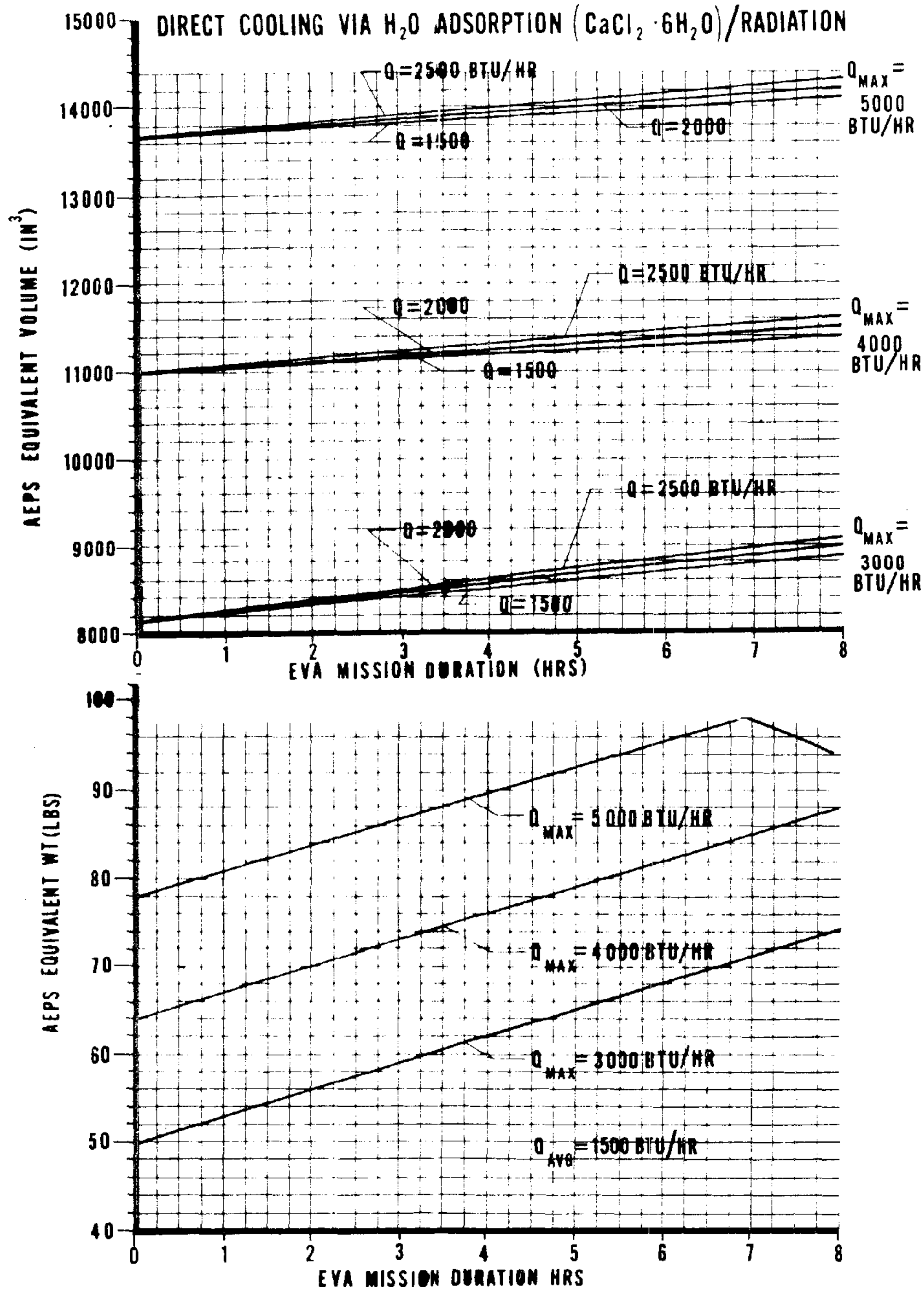
FIGURE 4–8. DIRECT COOLING VIA H_2O ADSORPTION/RADIATION

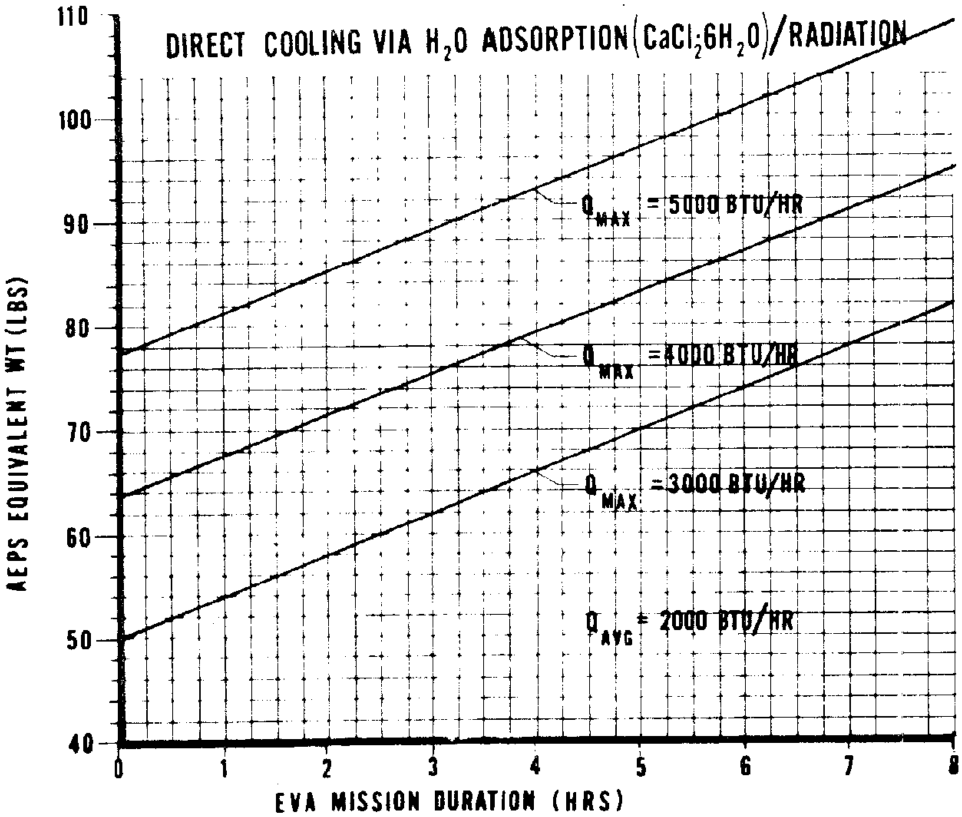

DIRECT COOLING VIA H_2O ADSORPTION ($LiBr \cdot 3H_2O$)/RADIATION
VEHICLE EQUIVALENT WT (LBS)
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
0
250
500
750
1000
1250
1500
0 1 2 3 4 5 6 7 8

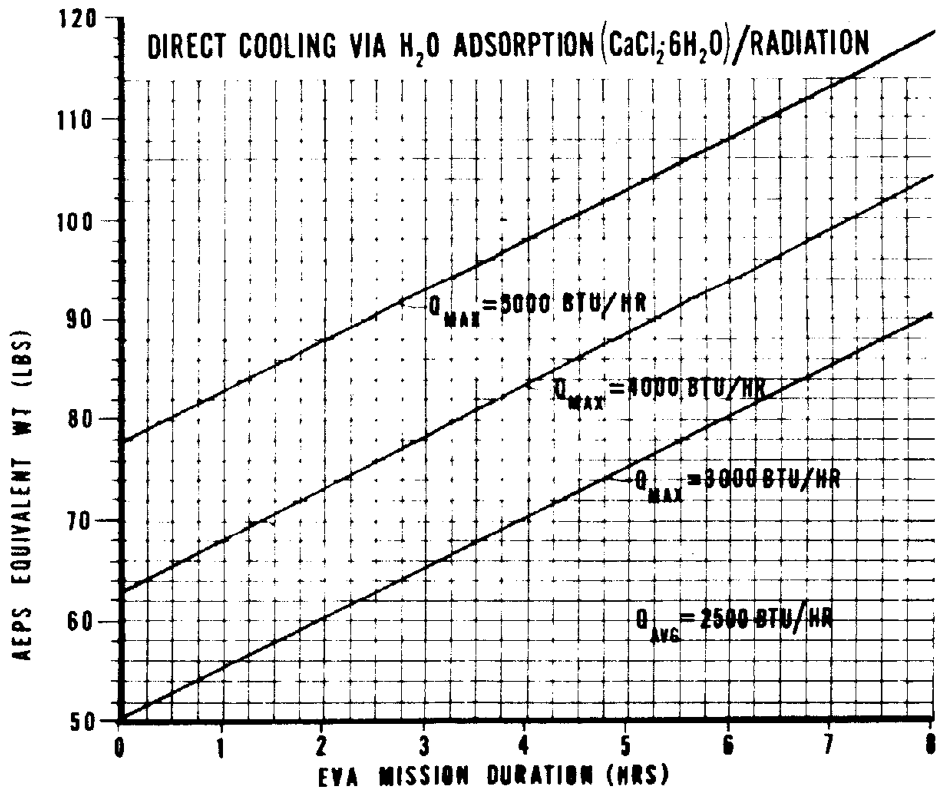

DIRECT COOLING VIA H_2O ADSORPTION ($LiBr \cdot 3H_2O$)/RADIATION
AEPS EQUIVALENT VOLUME (IN^3)
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=2000
Q=1500
Q_{MAX}=5000 BTU/HR
Q_{MAX}=4000 BTU/HR
Q_{MAX}=3000 BTU/HR
4000
5000
6000
7000
8000
9000
10000
0 1 2 3 4 5 6 7 8


DIRECT COOLING VIA H_2O ADSORPTION (LiBr·3H_2O)/RADIATION
Q=2500 BTU/HR
Q=2000
Q=1500
Q=5000 BTU/HR MAX
Q=2500 BTU/HR
Q=2000
Q=1500
Q=4000 BTU/HR MAX
Q=2500 BTU/HR
Q=2000
Q=1500
Q=3000 BTU/HR MAX
AEPS EQUIVALENT WT (LBS)
EVA MISSION DURATION (HRS)


DIRECT COOLING VIA H_2O ADSORPTION (CaCl$_2$·6H_2O)/RADIATION
Q=2500 btu/hr
Q=2000 btu/hr
Q=1500 btu/hr
Vehicle Equivalent Wt (lbs)
E V A Mission Duration (hrs)


DIRECT COOLING VIA H2O ADSORPTION (CaCl2 ·6H2O)/RADIATION
AEPS EQUIVALENT VOLUME (IN3)
Q=2500 BTU/HR
Q=1500
Q=2000
QMAX = 5000 BTU/HR
Q=2500 BTU/HR
Q=2000
Q=1500
QMAX = 4000 BTU/HR
Q=2500 BTU/HR
Q=2000
Q=1500
QMAX = 3000 BTU/HR
EVA MISSION DURATION (HRS)
AEPS EQUIVALENT WT (LBS)
QMAX = 5000 BTU/HR
QMAX = 4000 BTU/HR
QMAX = 3000 BTU/HR
QAVG = 1500 BTU/HR
EVA MISSION DURATION HRS


DIRECT COOLING VIA H_2O ADSORPTION ($CaCl_2 \cdot 6H_2O$)/RADIATION
Q_{MAX} = 5000 BTU/HR
Q_{MAX} = 4000 BTU/HR
Q_{MAX} = 3000 BTU/HR
Q_{AVG} = 2000 BTU/HR
AEPS EQUIVALENT WT (LBS)
EVA MISSION DURATION (HRS)
110
100
90
80
70
60
50
40
0
1
2
3
4
5
6
7
8


DIRECT COOLING VIA H_2O ADSORPTION ($CaCl_2 \cdot 6H_2O$)/RADIATION
Q_{MAX} = 5000 BTU/HR
Q_{MAX} = 4000 BTU/HR
Q_{MAX} = 3000 BTU/HR
Q_{AVG} = 2500 BTU/HR
AEPS EQUIVALENT WT (LBS)
EVA MISSION DURATION (HRS)
120
110
100
90
80
70
60
50
0
1
2
3
4
5
6
7
8

CONCEPT 9 - THERMAL STORAGE (ICE)

Thermal storage is a regenerable thermal control concept that utilizes the heat of fusion and the heat capacity of a material to provide thermal control. Direct cooling of the vent loop and the LCG is achieved in the thermal storage unit utilizing the heat of fusion of ice and superheating the water from 32 to 50°F. Vent loop humidity control is achieved by condensation of the water vapor in the thermal storage unit and separation and removal of the condensate by the water separator and holding tank. The TCV provides automatic LCG temperature control.

Regeneration of the thermal storage unit dictates the necessity for a vehicle refrigeration system. The thermal storage unit may be regenerated either by insertion of precooled ice cartridges or by incorporation of cooling coils within the thermal storage unit. If a cooling coil approach is employed, it may be necessary to add an intermediate coolant loop to prevent freeze-up of the LCG and/or the vent loop. This would slightly increase weight and volume.

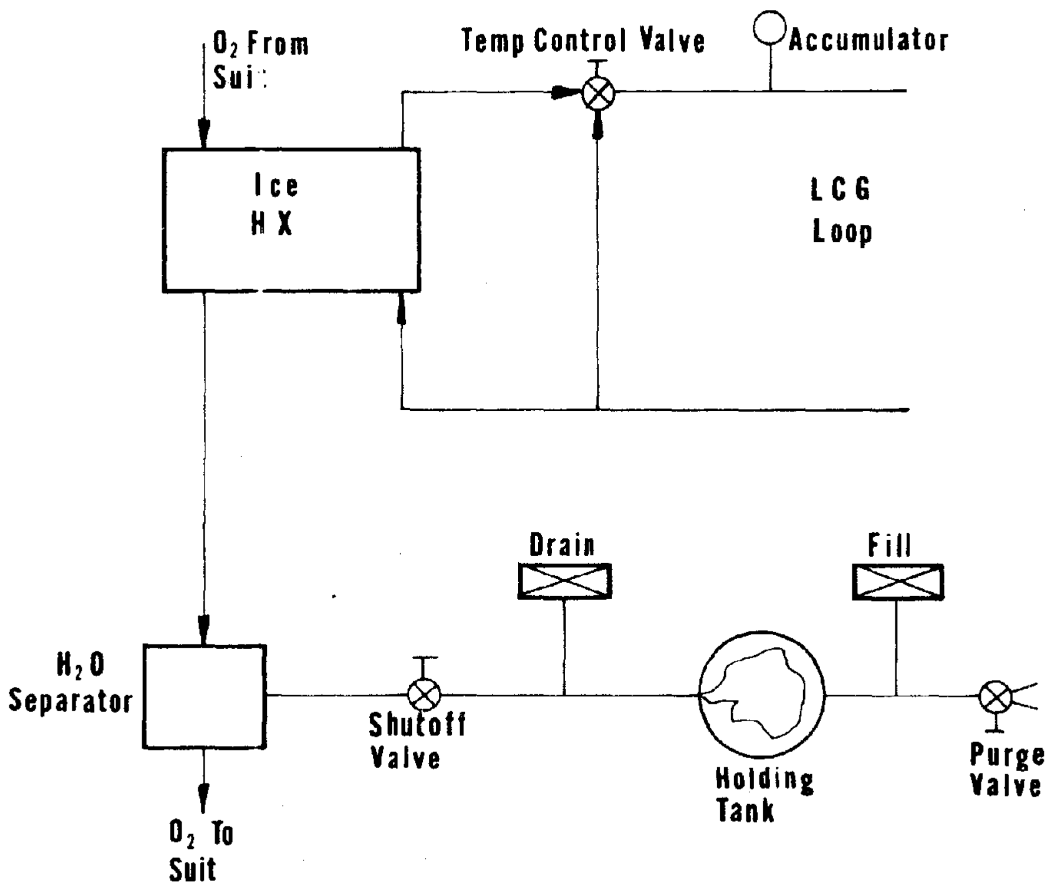
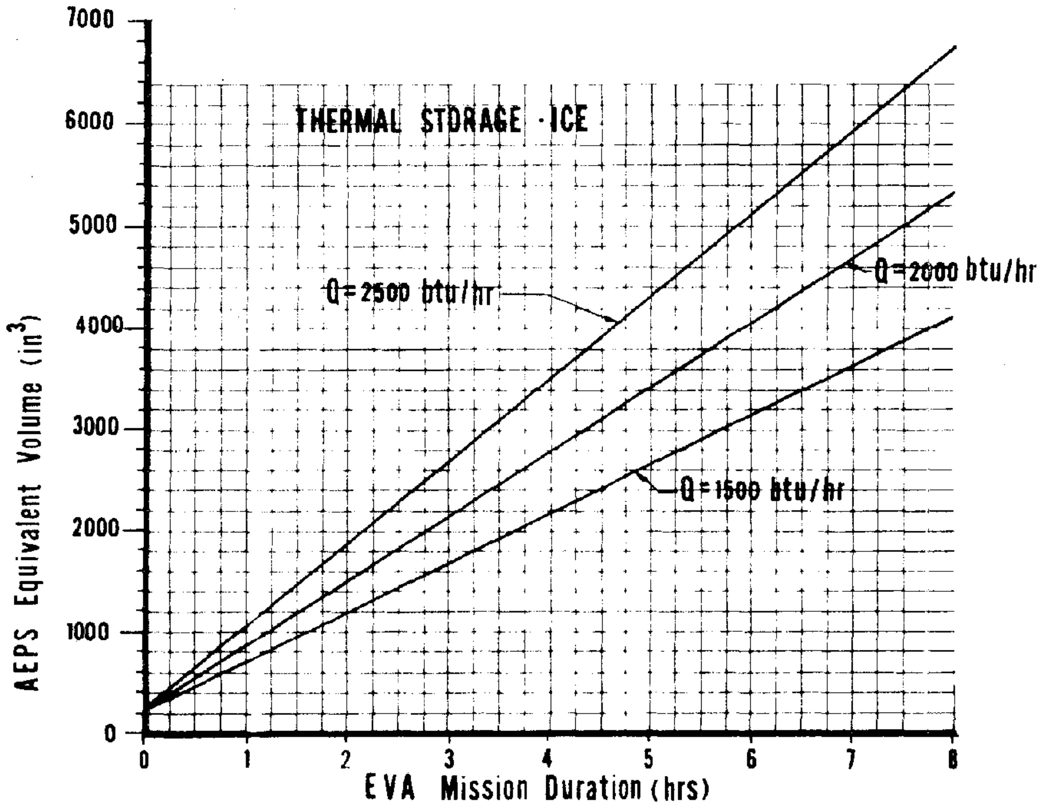
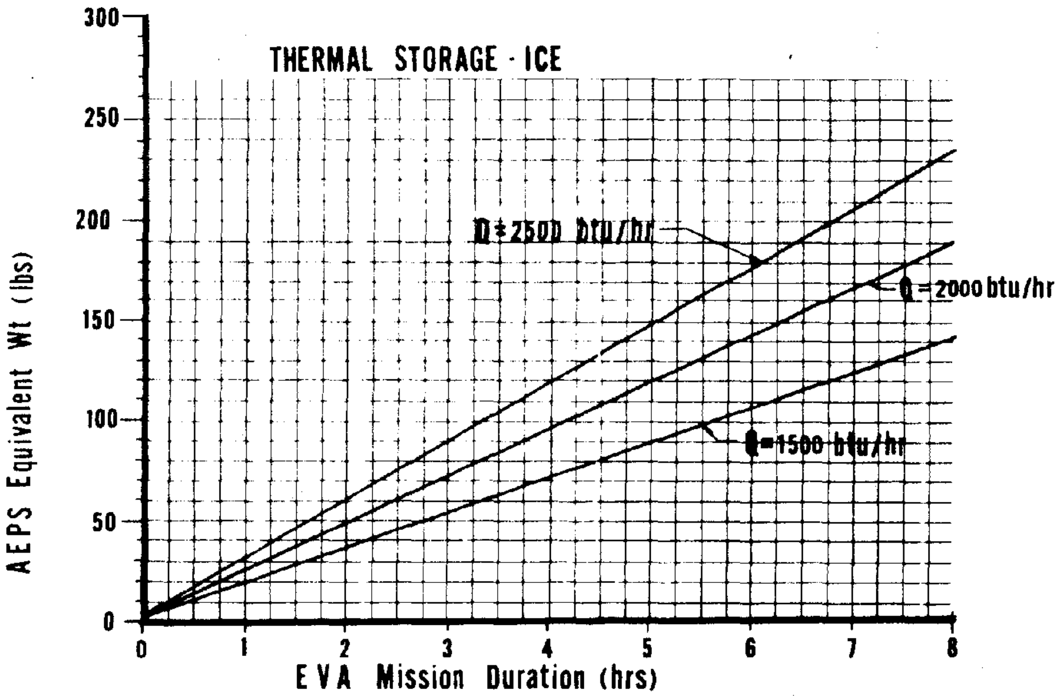


FIGURE 4–9. THERMAL STORAGE – ICE



THERMAL STORAGE - ICE
Q=2500 btu/hr
Q=2000 btu/hr
Q=1500 btu/hr
AEPS Equivalent Volume (in^3)
EVA Mission Duration (hrs)



THERMAL STORAGE - ICE
Q=2500 btu/hr
Q=2000 btu/hr
Q=1500 btu/hr
AEPS Equivalent Wt (lbs)
EVA Mission Duration (hrs)

CONCEPT 10 - THERMAL STORAGE (SUBCOOLED ICE)

Thermal storage utilizing subcooled ice is the extension of the previous concept which decreases AEPS volume and weight (by reducing amount of ice required) and increases vehicle penalty (by increasing energy required to regenerate and subcool the ice). This concept is comprised of a subcooled ice thermal storage unit, an intermediate coolant loop with a bypass valve and cryogenic fittings, and an O_2/LCG heat exchanger (schematically shown as two heat exchangers). The ice is subcooled to -250°F in the vehicle via the coolant line cryogenic fittings. Therefore, thermal storage capacity consists of subcooling, heat of fusion and superheating of water. System temperature control is provided by the coolant loop bypass valve which maintains a constant O_2/LCG heat exchanger inlet temperature and the TCV which provides LCG temperature control. A water separator and holding tank removes and stores vent loop condensate. The ice thermal storage unit requires development in regard to heat transfer and structural stressing from thermal expansion and contraction.

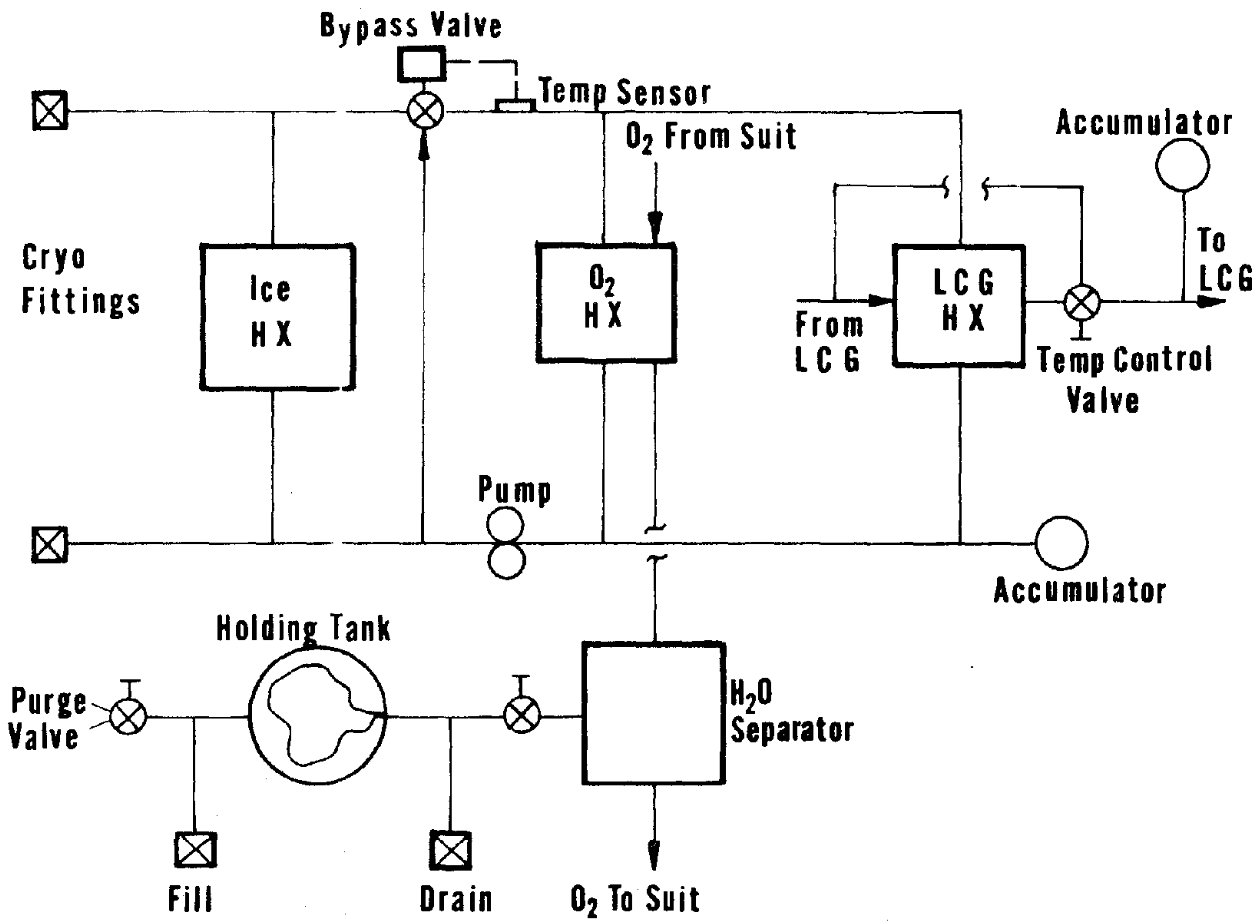
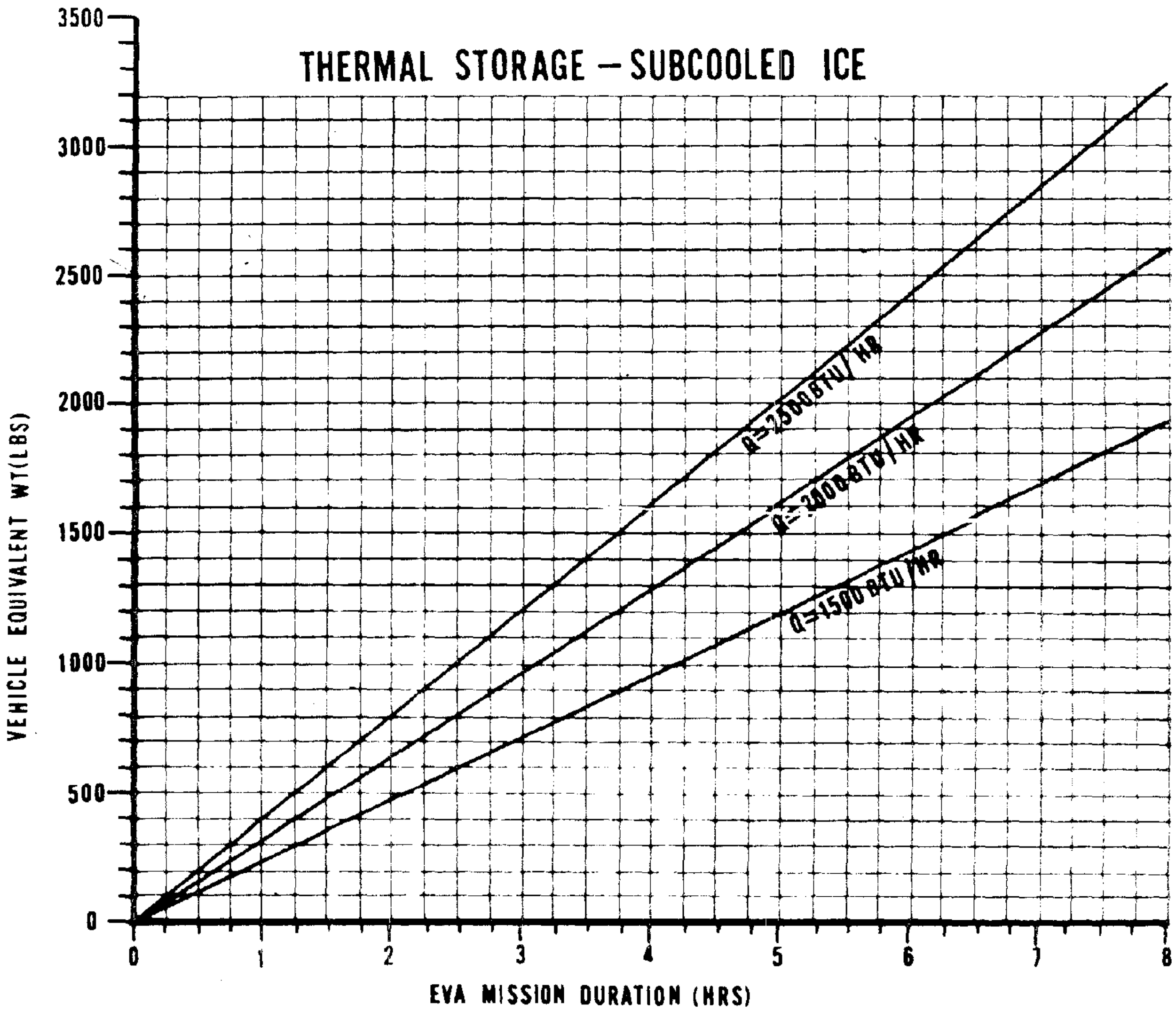
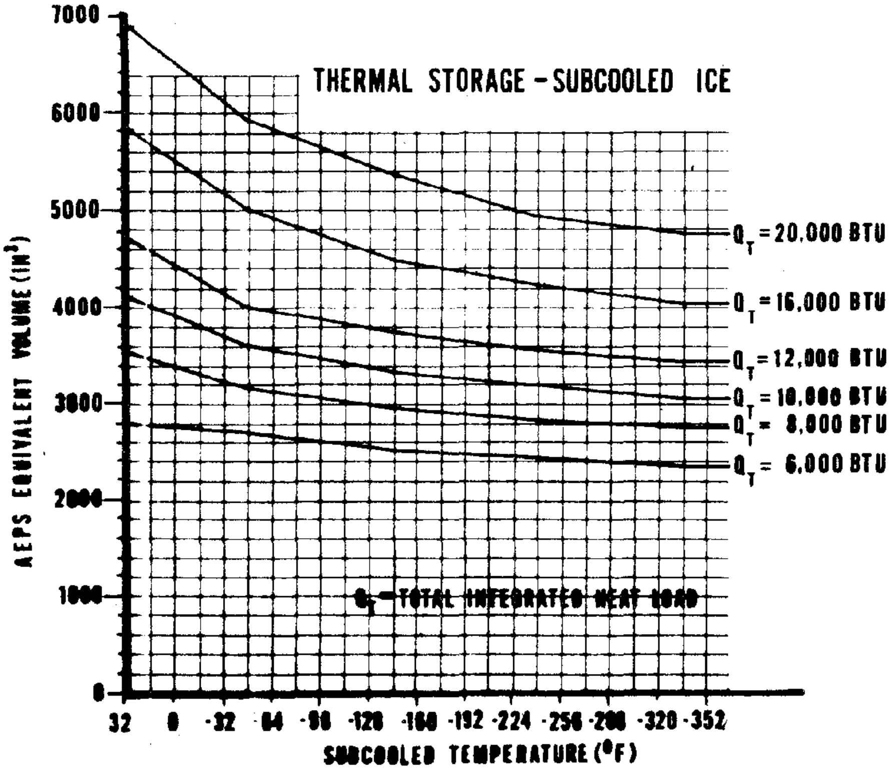
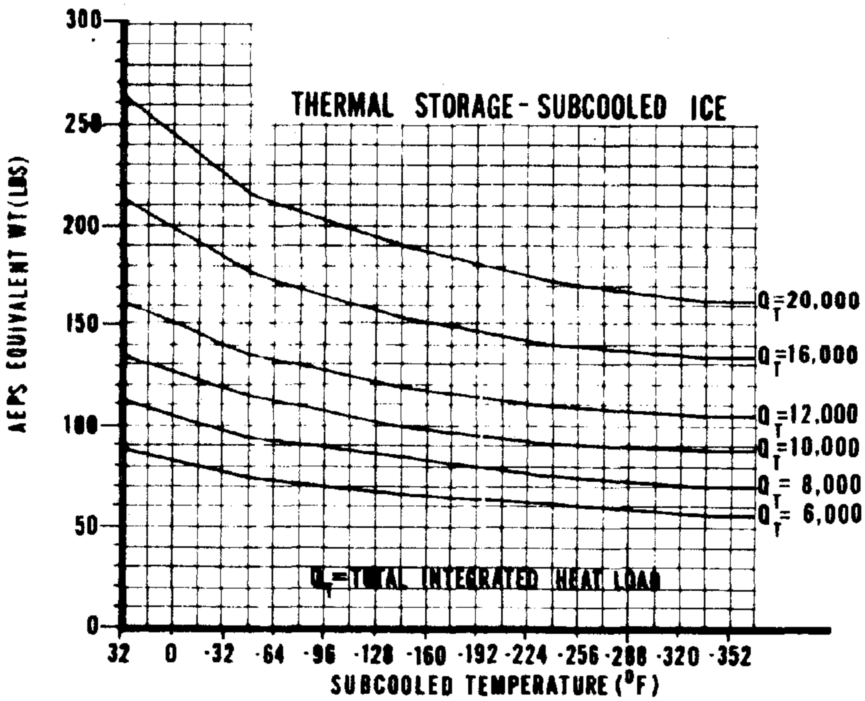


FIGURE 4–10. THERMAL STORAGE – SUBCOOLED ICE


THERMAL STORAGE – SUBCOOLED ICE
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
VEHICLE EQUIVALENT WT(LBS)
3500
3000
2500
2000
1500
1000
500
0
EVA MISSION DURATION (HRS)
0
1
2
3
4
5
6
7
8


THERMAL STORAGE - SUBCOOLED ICE
AEPS EQUIVALENT VOLUME (IN³)
SUBCOOLED TEMPERATURE (°F)
Q_T = 20,000 BTU
Q_T = 16,000 BTU
Q_T = 12,000 BTU
Q_T = 10,000 BTU
Q_T = 8,000 BTU
Q_T = 6,000 BTU
Q_T = TOTAL INTEGRATED HEAT LOAD


THERMAL STORAGE - SUBCOOLED ICE
AEPS EQUIVALENT WT (LBS)
SUBCOOLED TEMPERATURE (°F)
Q_T = 20,000
Q_T = 16,000
Q_T = 12,000
Q_T = 10,000
Q_T = 8,000
Q_T = 6,000
Q_T = TOTAL INTEGRATED HEAT LOAD

CONCEPT 11 - THERMAL STORAGE (PH_4Cl)

Thermal storage utilizing phosphonium chloride (PH_4Cl) is a self-regenerable thermal control concept. PH_4Cl is a chemical that has a heat of fusion of 324 BTU/lb at 82°F and 48 atmospheres pressure and has an estimated specific gravity of 1.7. It is formed at low temperature from phosphine (PH_3) and hydrogen chloride (HCl). A vapor compression intermediate loop is utilized to raise the desired coolant temperature of 50°F at the O_2/LCG heat exchanger to 82°F at the thermal storage unit. Humidity control is furnished by a water separator and holding tank which remove and store vent loop condensate. Vehicle penalties associated with this concept are relatively low, since PH_4Cl will resolidify of its own accord at normal cabin temperatures.

Solid PH_4Cl sublimates at pressures below 700 psia at room temperature. As pressure is decreased further, gaseous PH_4Cl dissociates into two gases: (1) Hydrogen chloride and (2) Phosphine (PH_3). PH_3 is highly toxic and therefore, the thermal storage unit has been concepted so as to minimize the probability of any failure resulting in external leakage.

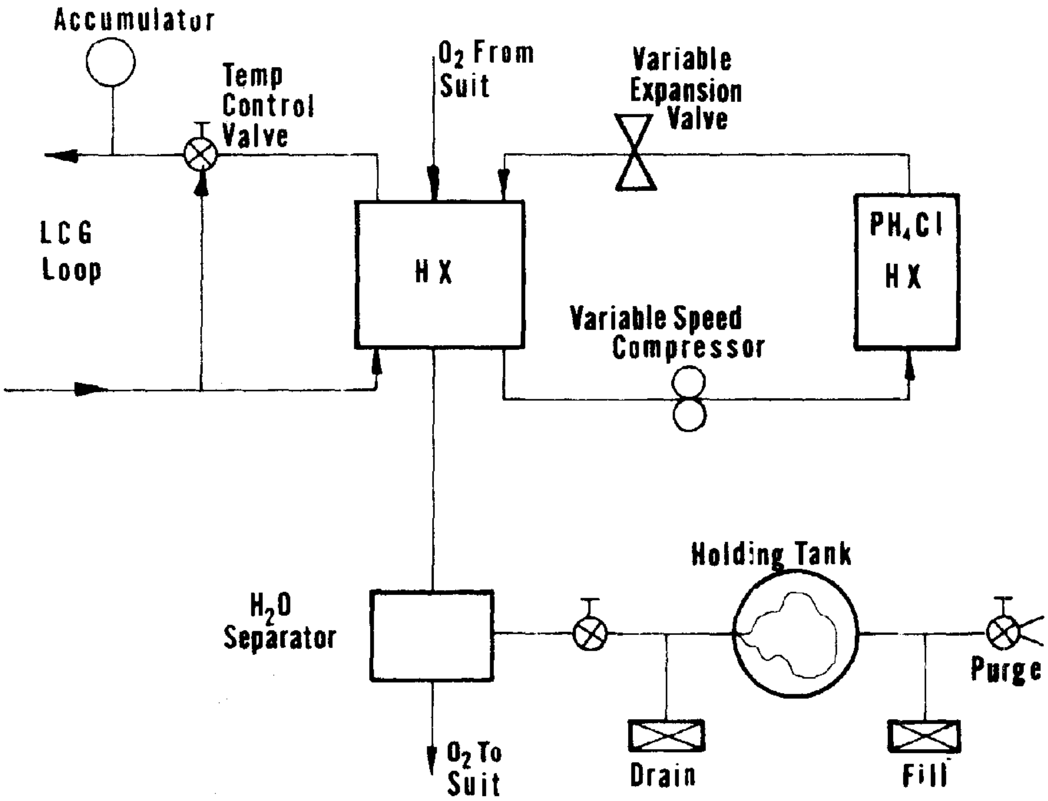
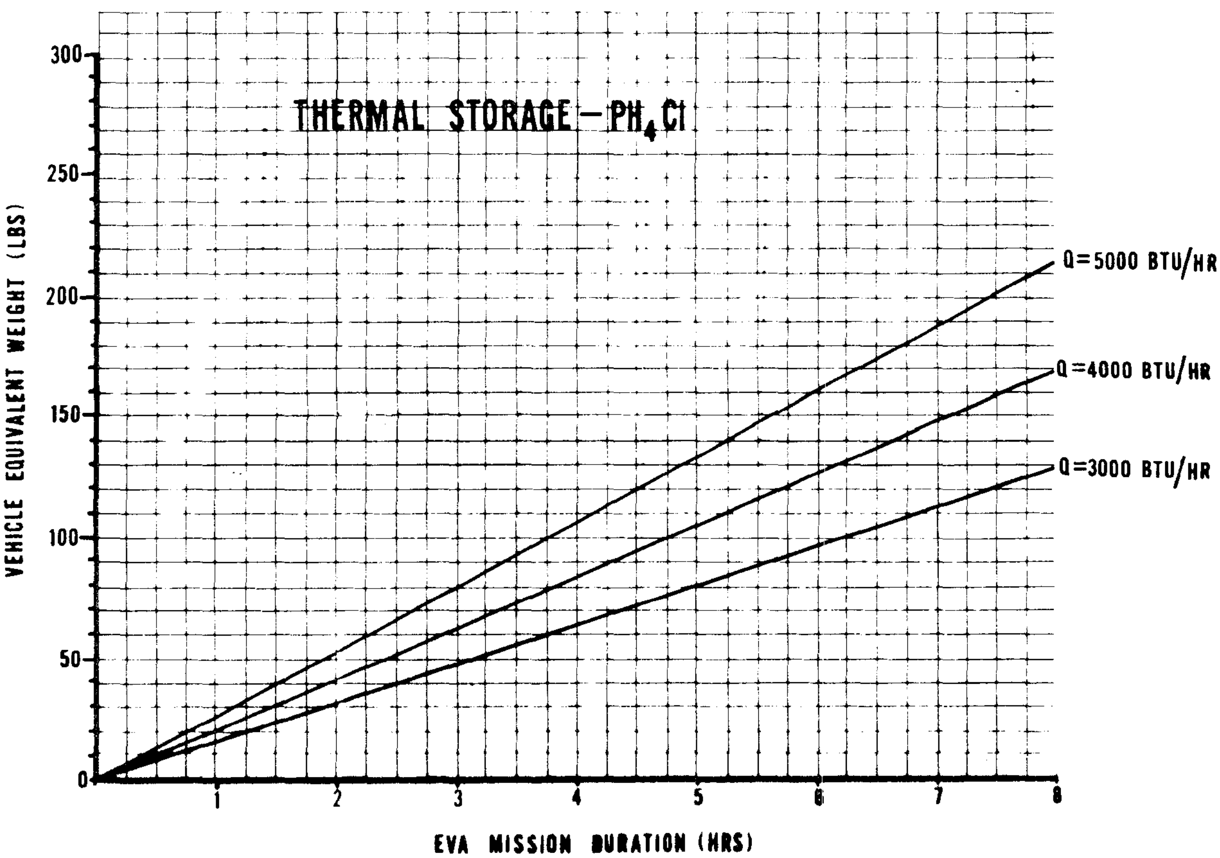
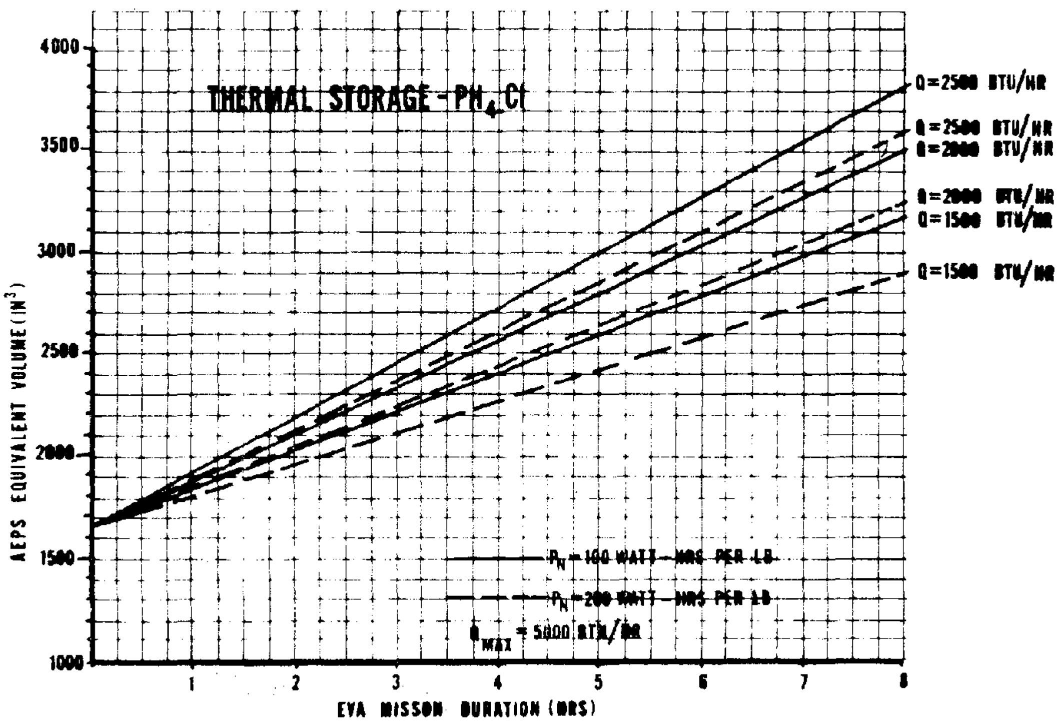
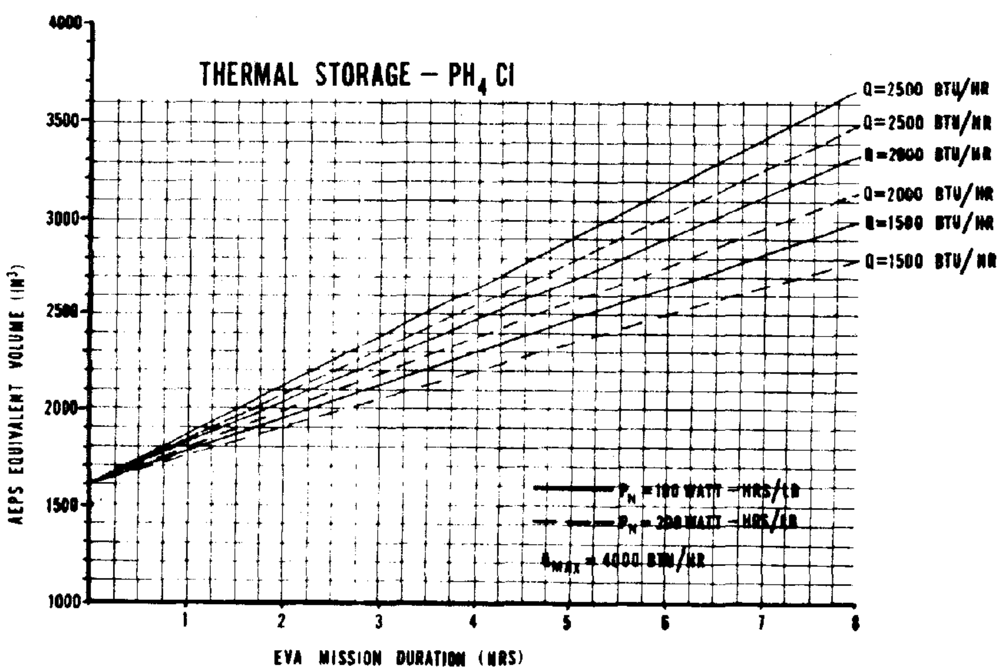


FIGURE 4–11. THERMAL STORAGE – PH_4Cl

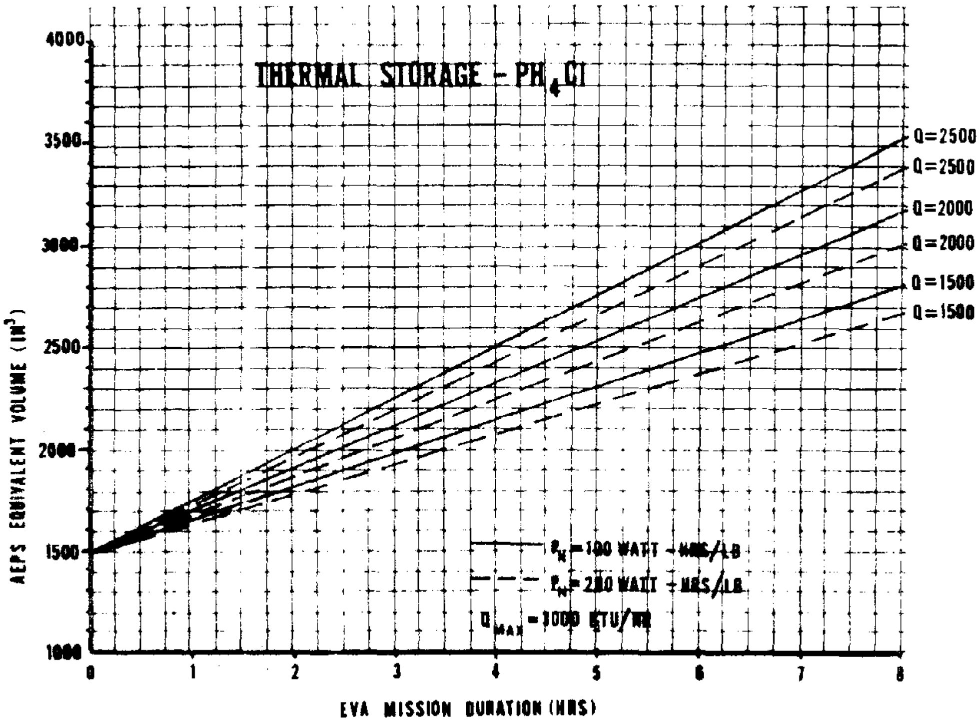

THERMAL STORAGE – PH_4Cl
VEHICLE EQUIVALENT WEIGHT (LBS)
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)
Q=5000 BTU/HR
Q=4000 BTU/HR
Q=3000 BTU/HR



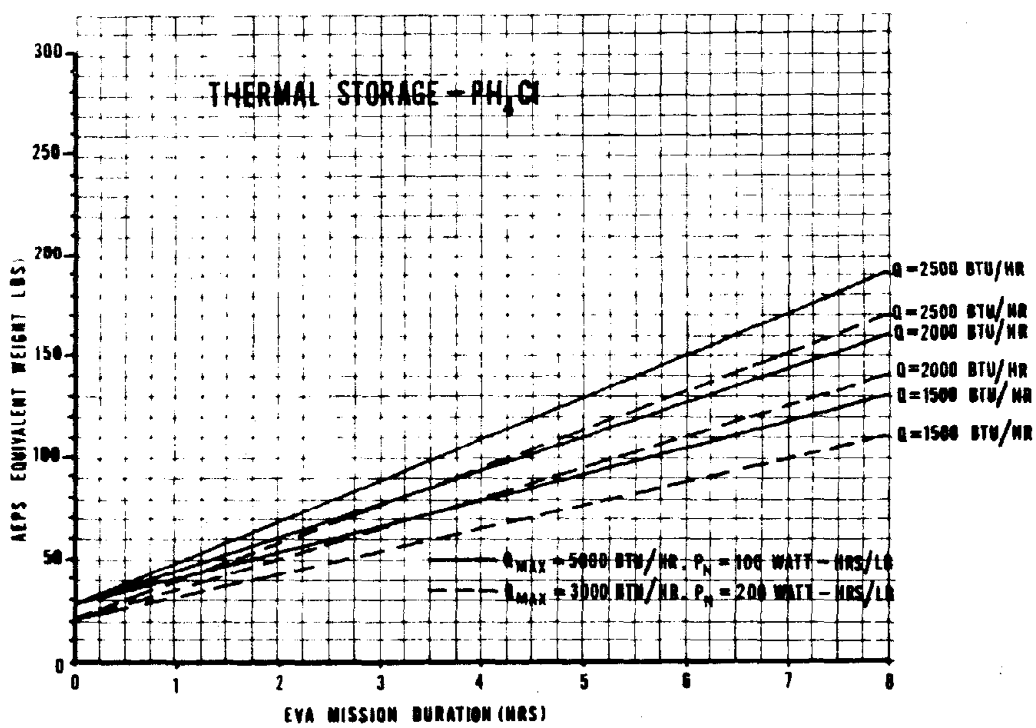
THERMAL STORAGE - PH_4Cl
AEPS EQUIVALENT VOLUME (IN^3)
EVA MISSON DURATION (HRS)
Q=2500 BTU/HR
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
Q=1500 BTU/HR
P_N = 100 WATT - HRS PER LB
P_N = 200 WATT - HRS PER LB
Q_{MAX} = 5000 BTU/HR



THERMAL STORAGE – PH_4 Cl
AEPS EQUIVALENT VOLUME (IN^3)
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
Q=1500 BTU/HR
P_N = 100 WATT - HRS/LB
P_N = 200 WATT - HRS/LB
Q_{MAX} = 4000 BTU/HR



THERMAL STORAGE - PH_4Cl
4000
3500
3000
2500
2000
1500
1000
AEPS EQUIVALENT VOLUME (IN^3)
Q=2500
Q=2500
Q=2000
Q=2000
Q=1500
Q=1500
P_N = 100 WATT - HRS/LB
P_N = 200 WATT - HRS/LB
Q_{MAX} = 3000 BTU/HR
0 1 2 3 4 5 6 7 8
EVA MISSION DURATION (HRS)



THERMAL STORAGE - PH_4Cl
300
250
200
150
100
50
0
AEPS EQUIVALENT WEIGHT LBS)
Q = 2500 BTU/HR
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
Q = 1500 BTU/HR
Q_{MAX} = 5000 BTU/HR, P_N = 100 WATT - HRS/LB
Q_{MAX} = 3000 BTU/HR, P_N = 200 WATT - HRS/LB
0 1 2 3 4 5 6 7 8
EVA MISSION DURATION (HRS)

CONCEPT 12 - EXPENDABLE/DIRECT RADIATIVE COOLING

This concept is a hybrid concept which consists of a water boiler and radiator connected in parallel through the LCG temperature control valve. The temperature control valve selects what percentage of the heat load from the LCG is shared by each subsystem. The radiator is sized to handle the average heat load while the water boiler handles peak loads, thus radiator size and water expended in the boiler are minimized.

Humidity control is provided by a condensing heat exchanger and a water separator which feeds the separated water to the water boiler to provide additional cooling capacity. For low or no load conditions, a variable conductance area or emissivity device must be utilized to prevent over-cooling of the LCG. As is the case in the direct radiation concept, normal maintenance is required to sustain radiator performance. Because of its size, this concept is not applicable to "worn or carried" and, therefore, is eliminated from consideration for Space Station applications.

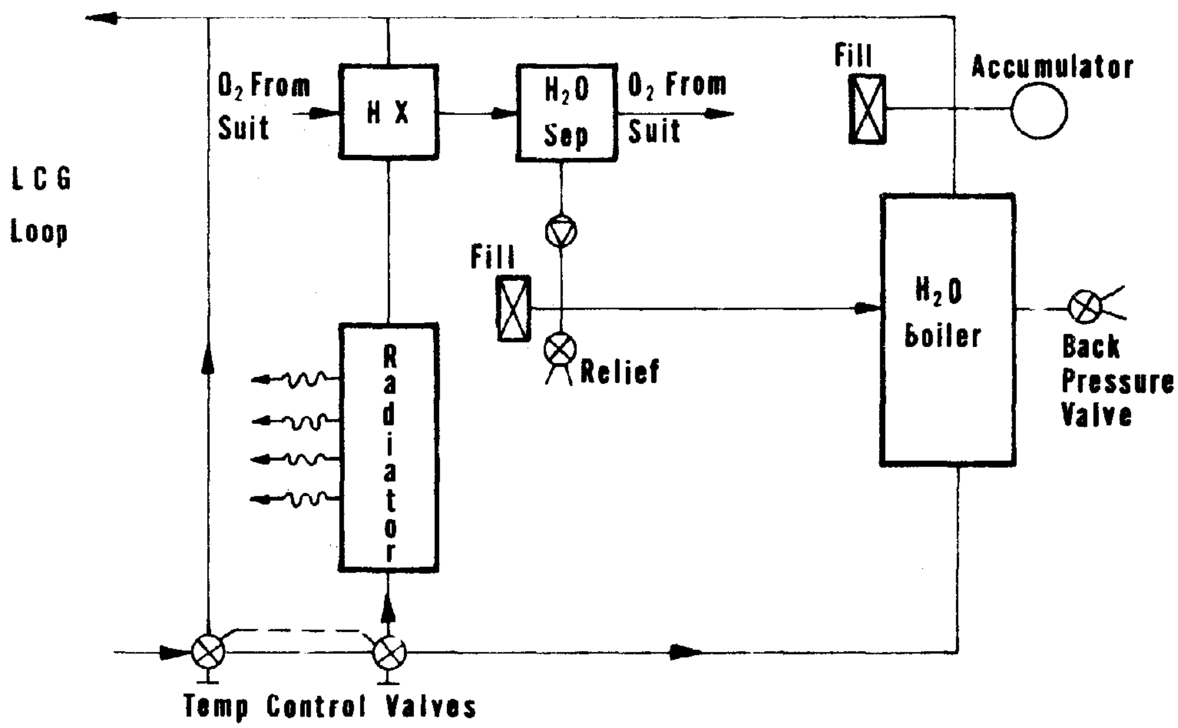
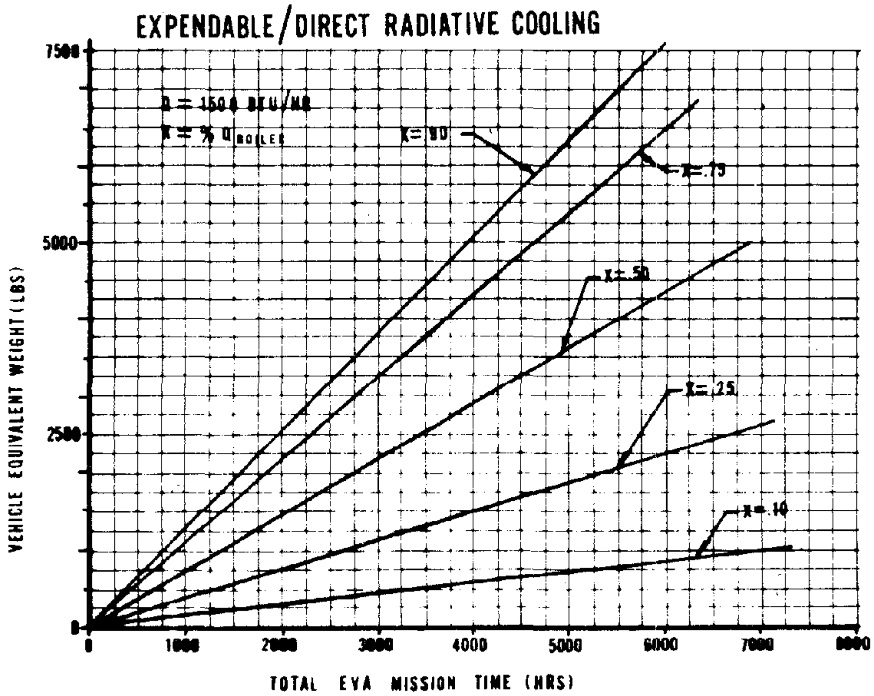
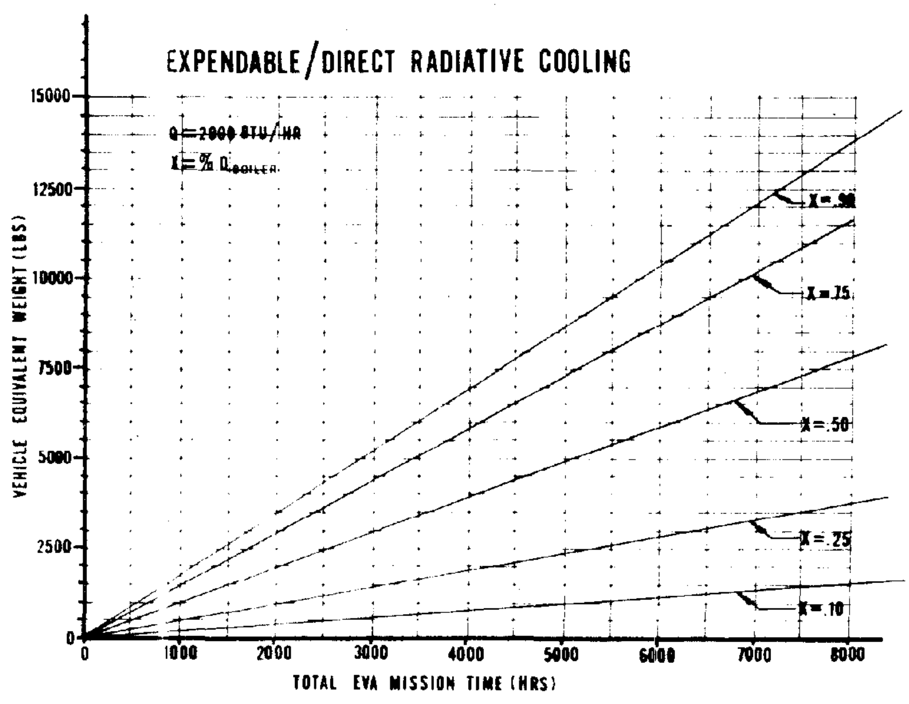
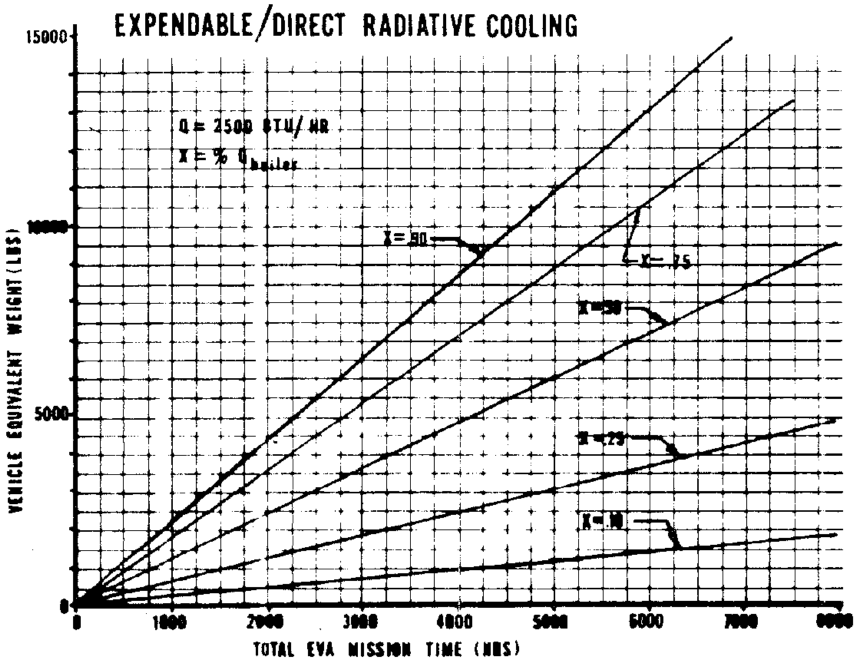


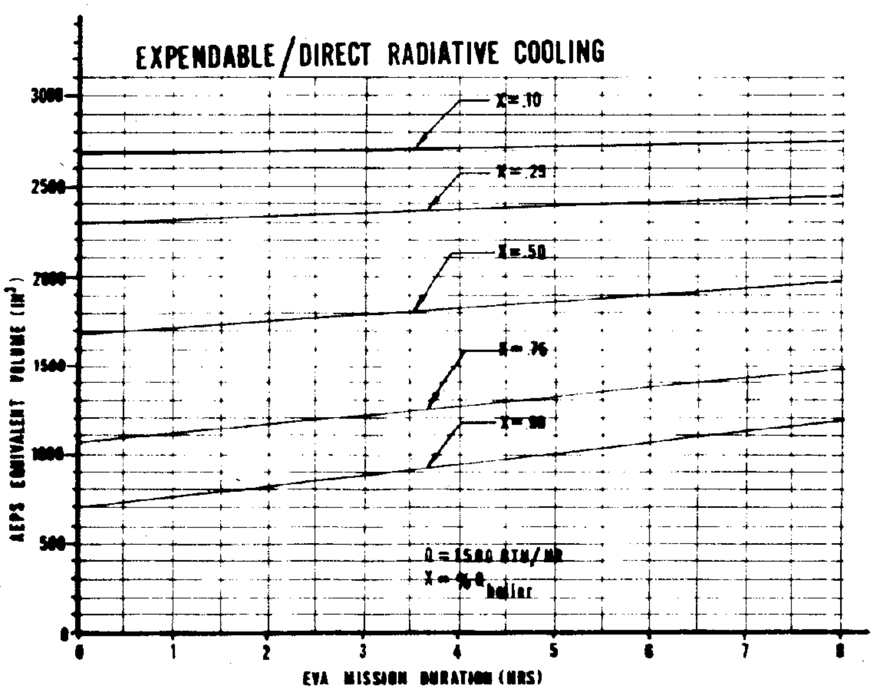
FIGURE 4–12. EXPENDABLE/DIRECT RADIATIVE COOLING


EXPENDABLE/DIRECT RADIATIVE COOLING
Q = 1500 BTU/HR
X = % Q BOILER
X=.90
X=.75
X=.50
X=.25
X=.10
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)
0
2500
5000
7500
1000
2000
3000
4000
5000
6000
7000
8000

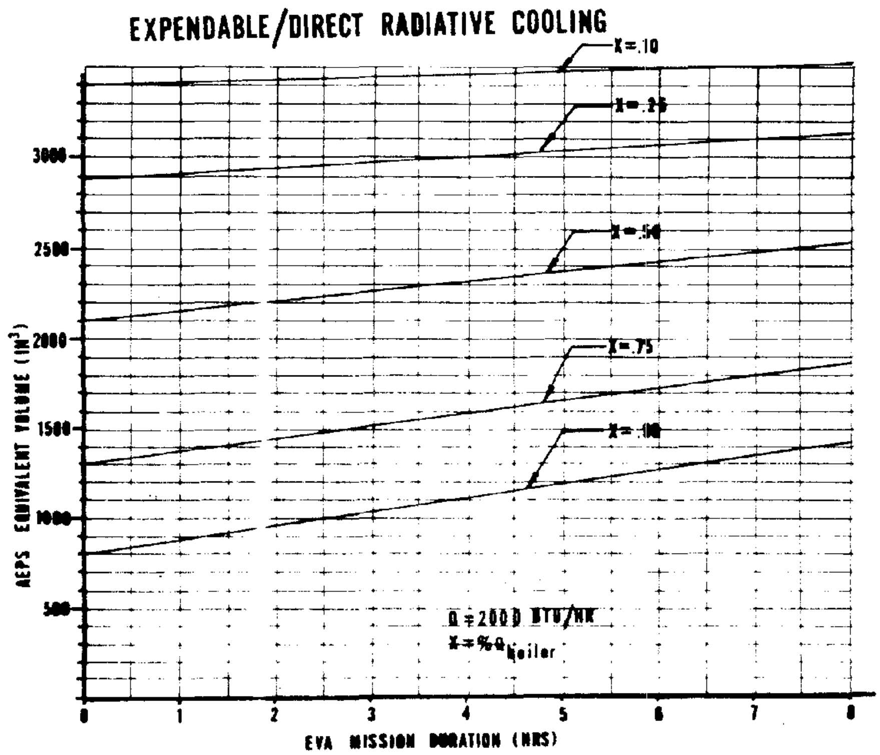

EXPENDABLE/DIRECT RADIATIVE COOLING
Q = 2000 BTU/HR
X = % Q BOILER
X=.90
X=.75
X=.50
X=.25
X=.10
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)
0
2500
5000
7500
10000
12500
15000
1000
2000
3000
4000
5000
6000
7000
8000

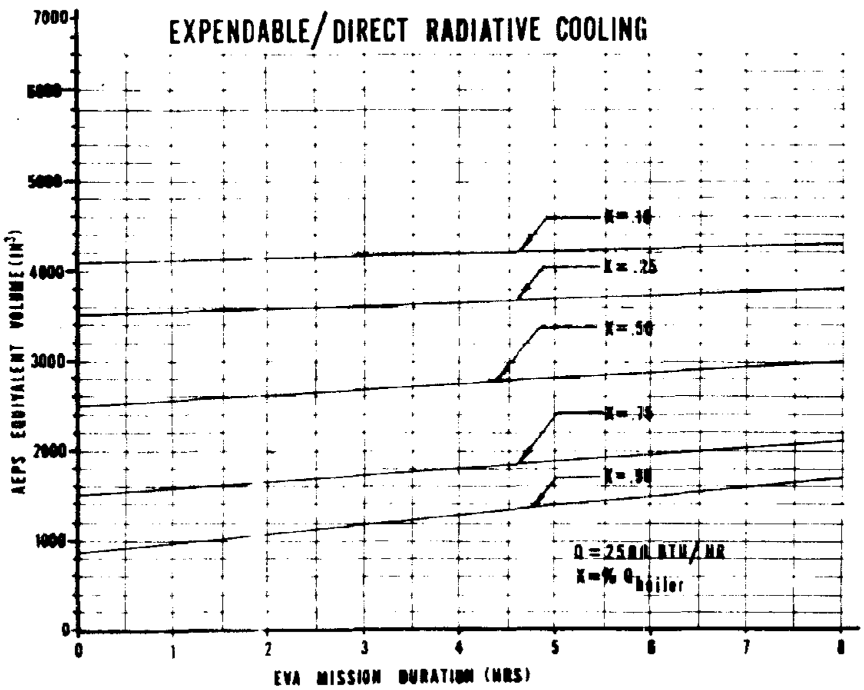


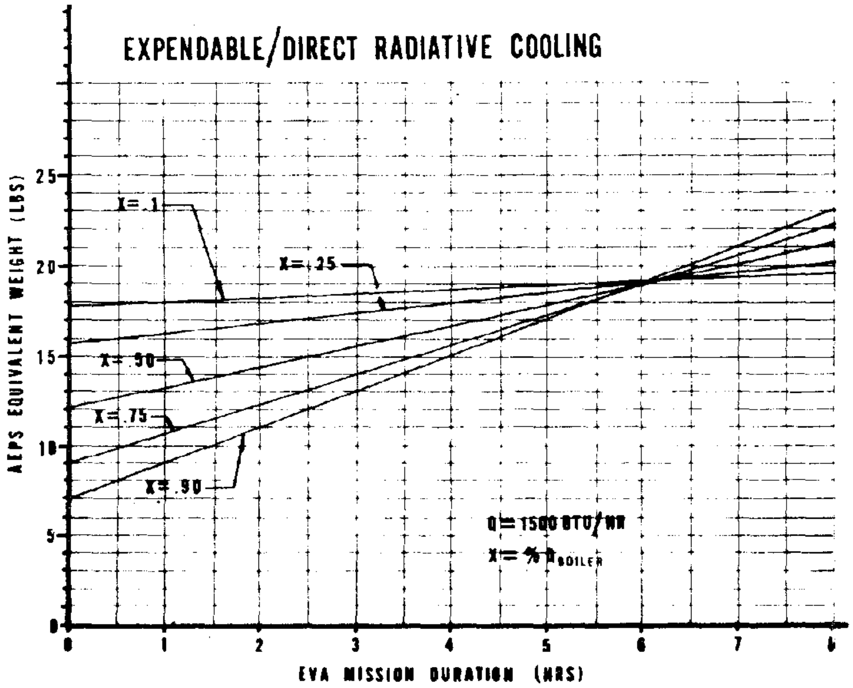
EXPENDABLE/DIRECT RADIATIVE COOLING
Q = 2500 BTU/HR
X = % Q boiler
X = .90
X = .75
X = .50
X = .25
X = .10
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)

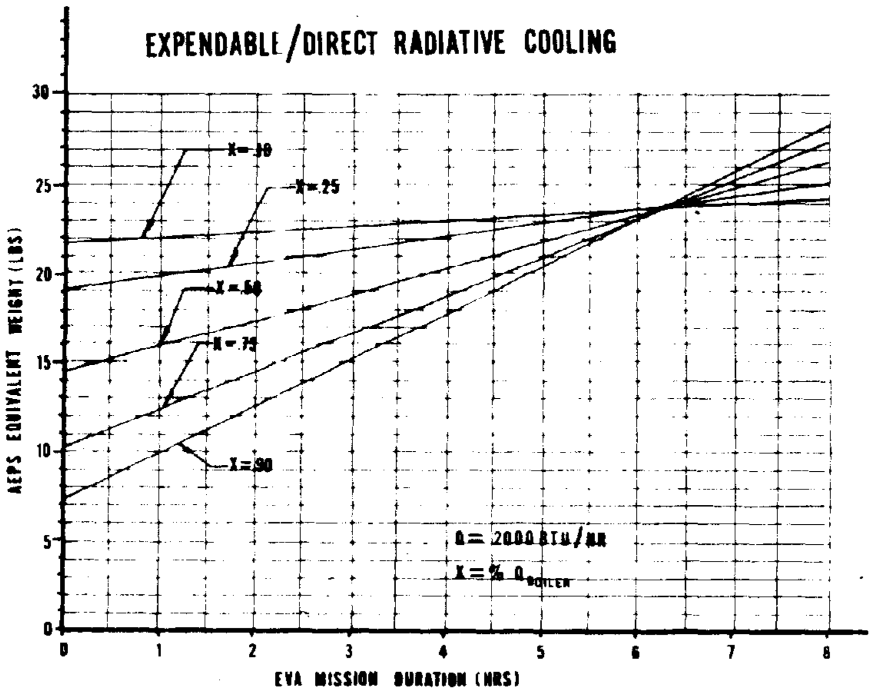


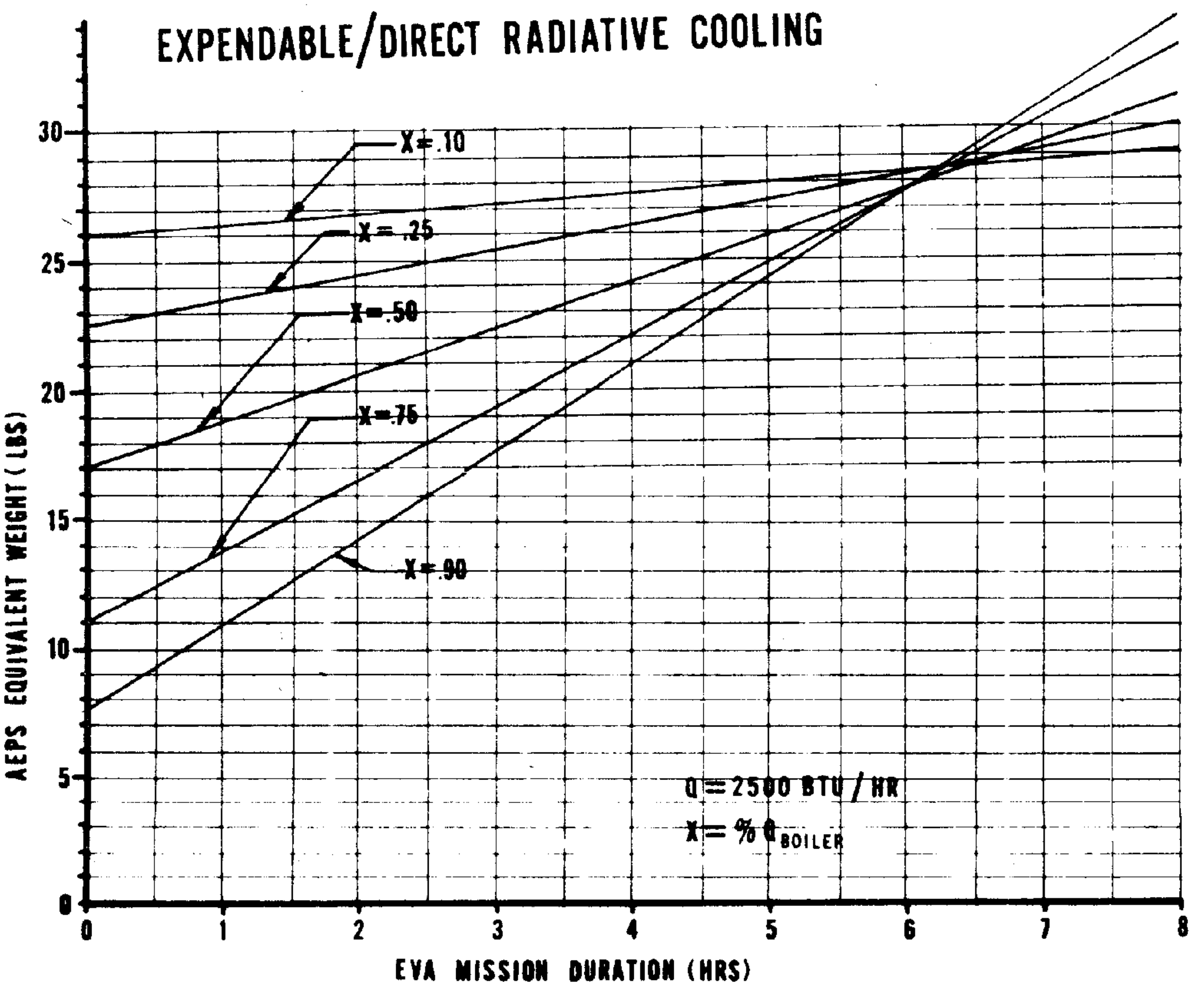
EXPENDABLE/DIRECT RADIATIVE COOLING
X = .10
X = .25
X = .50
Q = 1500 BTU/HR
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)


EXPENDABLE/DIRECT RADIATIVE COOLING
X=.10
X=.25
X=.50
X=.75
X=.90
AEPS EQUIVALENT VOLUME (IN³)
3000
2500
2000
1500
1000
500
Q=2000 BTU/HR
X=% Q boiler
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


EXPENDABLE/DIRECT RADIATIVE COOLING
7000
6000
5000
4000
3000
2000
1000
0
X=.10
X=.25
X=.50
X=.75
X=.90
AEPS EQUIVALENT VOLUME (IN³)
Q=2500 BTU/HR
X=% Q boiler
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


EXPENDABLE/DIRECT RADIATIVE COOLING
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
X = .1
X = .25
X = .50
X = .75
X = .90
Q = 1500 BTU/HR
X = % Q BOILER


EXPENDABLE/DIRECT RADIATIVE COOLING
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
X = .25
X = .75
X = .90
Q = 2000 BTU/HR
X = % Q BOILER


EXPENDABLE/DIRECT RADIATIVE COOLING
X = .10
X = .25
X = .50
X = .75
X = .90
Q = 2500 BTU / HR
X = % Q BOILER
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
0
5
10
15
20
25
30
1
2
3
4
6
7
8

CONCEPT 13 - EXPENDABLE/RADIATION

This hybrid concept consists of a radiator/vapor compression cycle and a water boiler connected in parallel through an automatic LCG temperature control valve. The temperature control valve selects what percentage of the heat load from the LCG is shared by each subsystem. The radiator/vapor compression subsystem is sized to handle the average LCG heat load plus the heat load from the vent system while the H_2O boiler handles peak heat loads. This minimizes radiator size, compressor size, and power consumption as well as water expended in the boiler.

Hūmidity control is provided by the vapor compression cycle evaporator and the water separator which feeds the separated water to the water boiler to provide additional cooling capacity. For low or no load conditions, a variable speed compressor and variable expansion valve are required to prevent over-cooling at the evaporator. As in the case of the direct radiation concept, normal maintenance is required to sustain radiator performance.

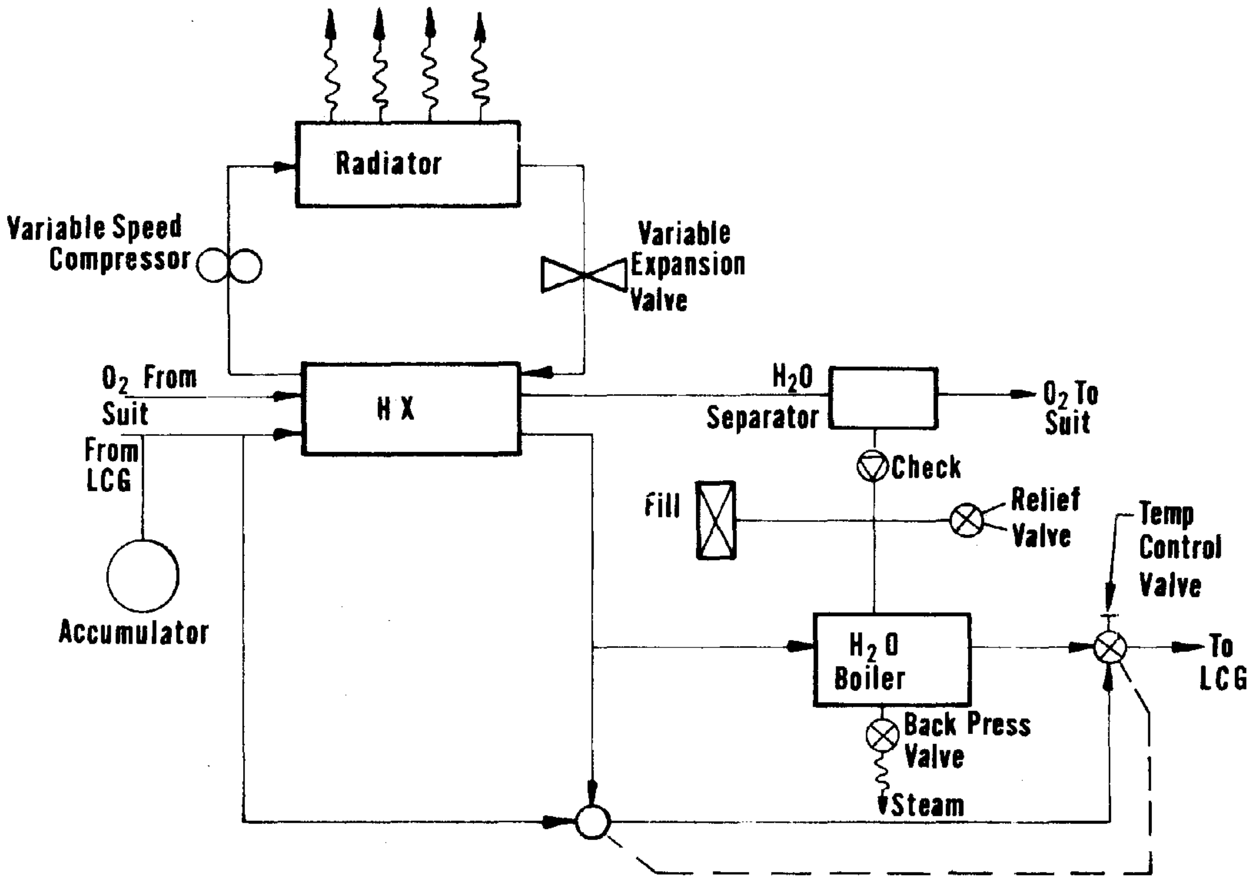
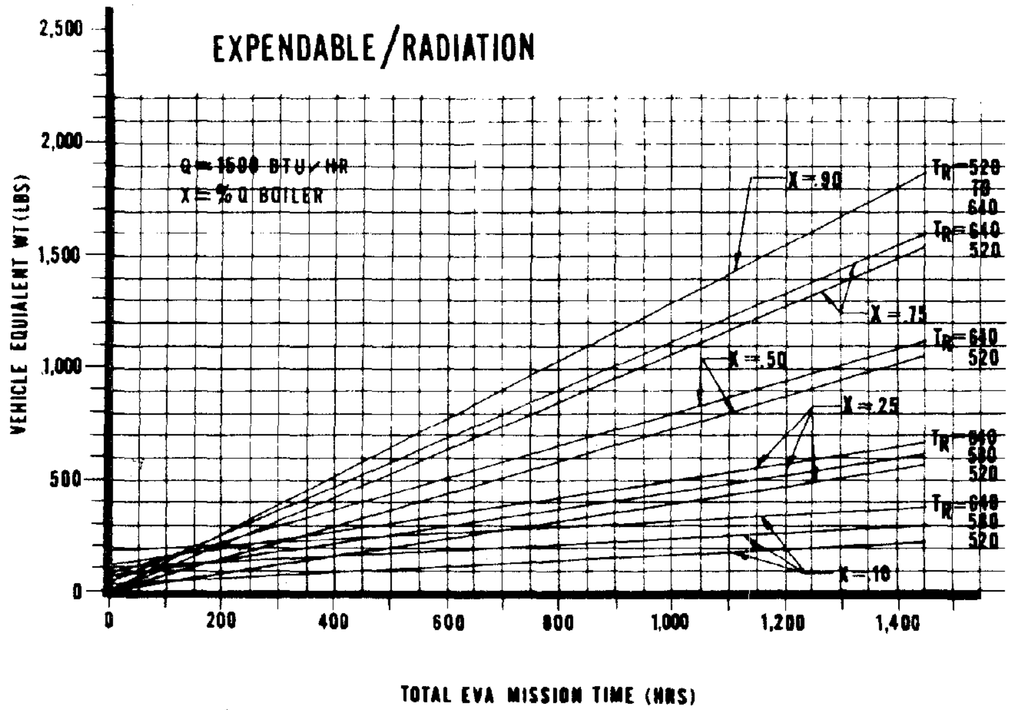
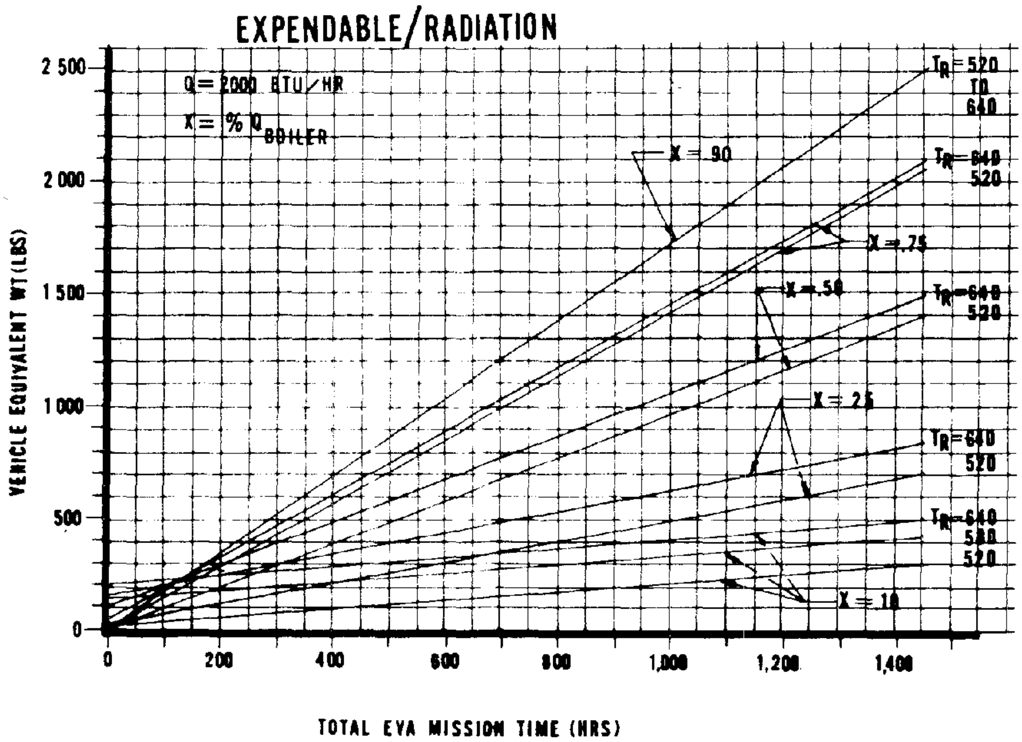


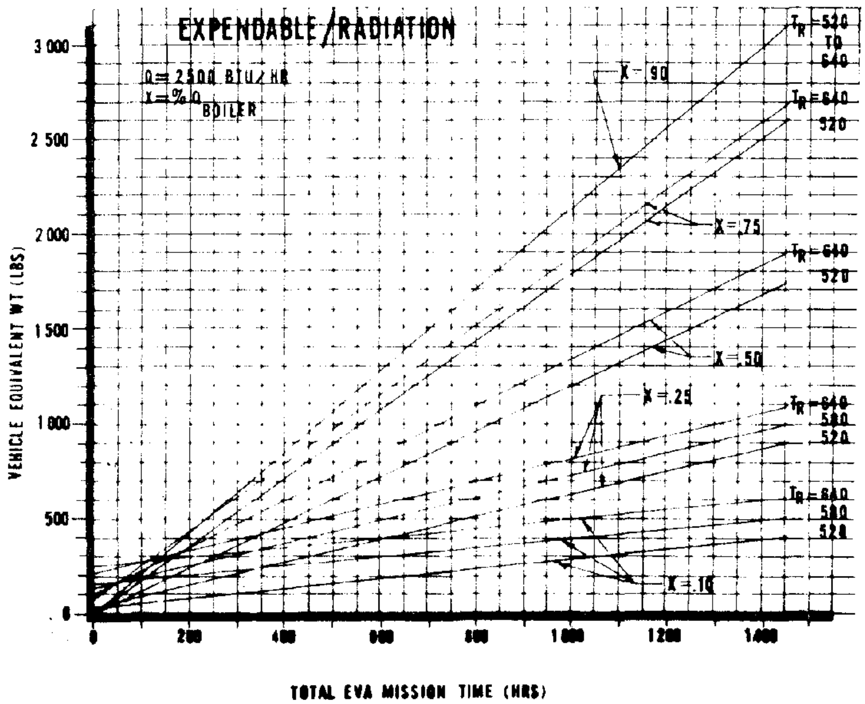
FIGURE 4--13. EXPENDABLE/RADIATION

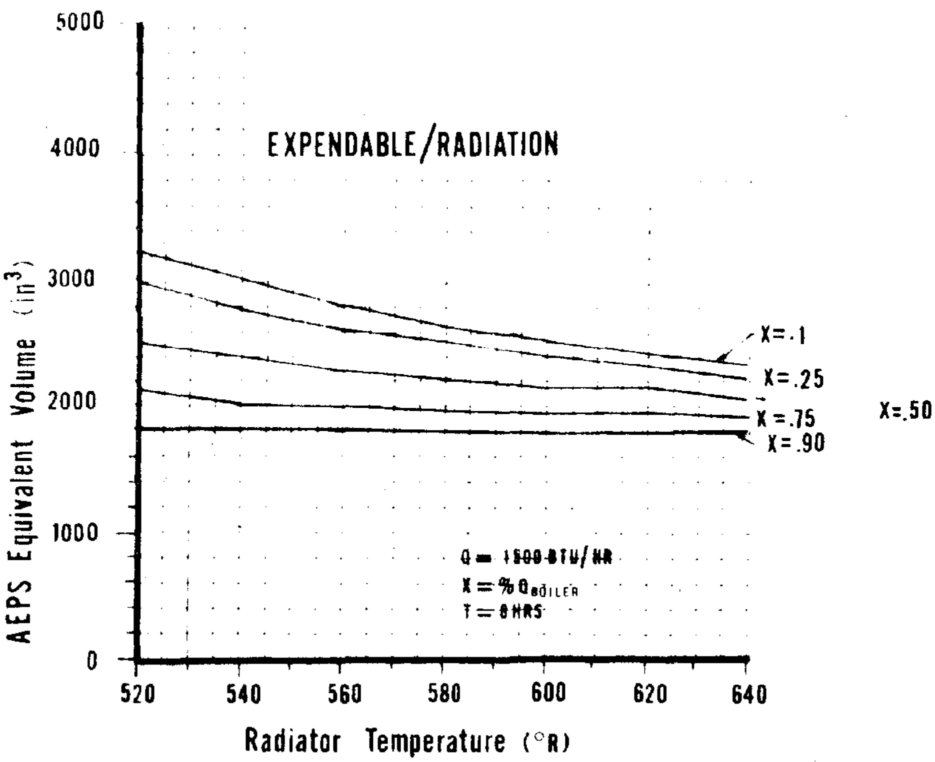


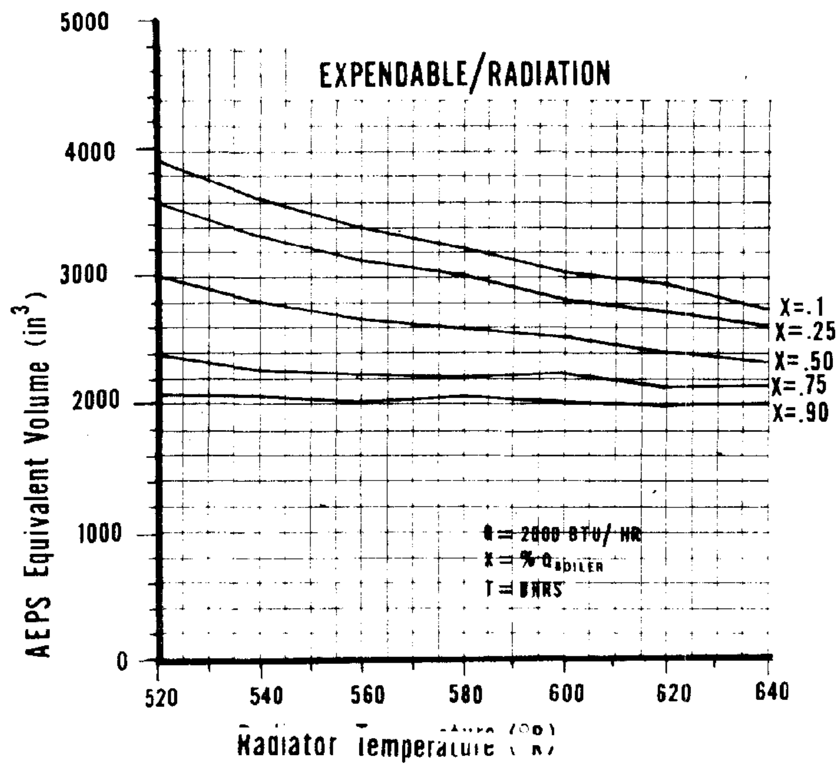
EXPENDABLE/RADIATION
Q = 1500 BTU/HR
X = % Q BOILER
X = .90
X = .75
X = .50
X = .25
X = .10
VEHICLE EQUIALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)

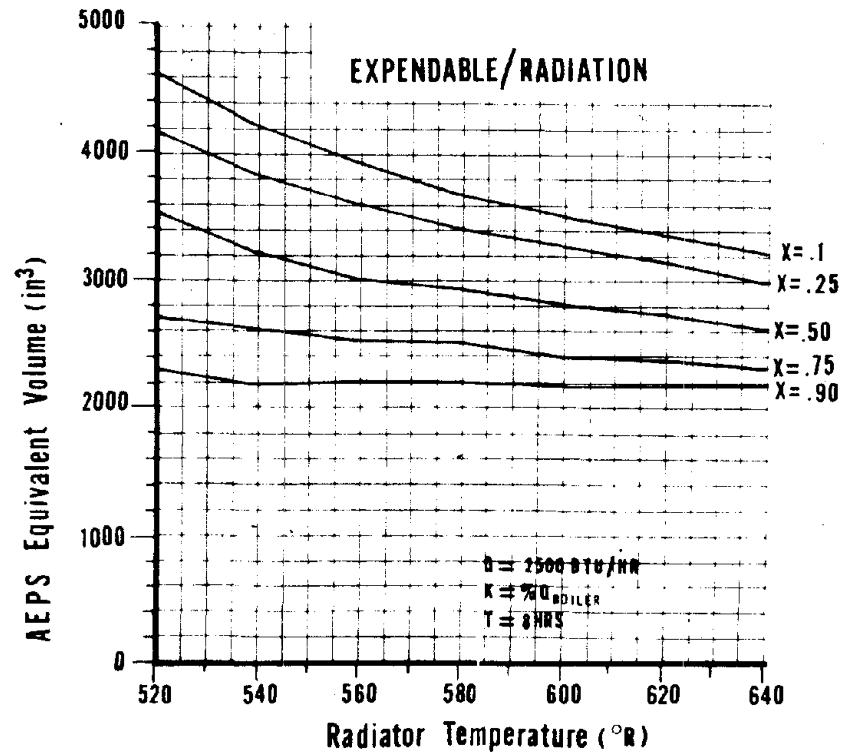


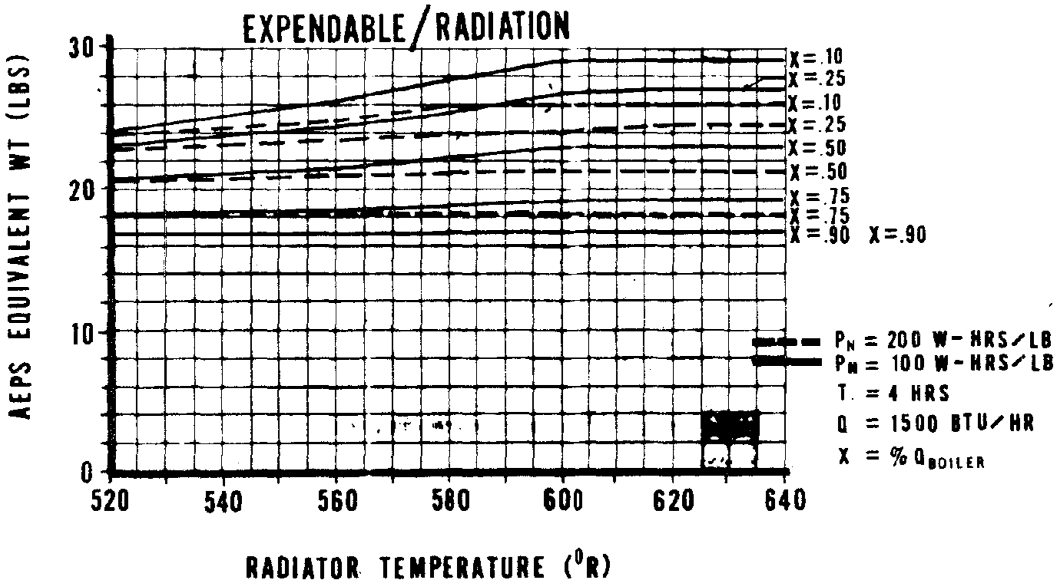
EXPENDABLE/RADIATION
Q = 2000 BTU/HR
X = % Q BOILER
X = .90
X = .75
X = .50
X = .25
X = .10
VEHICLE EQUIVALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)

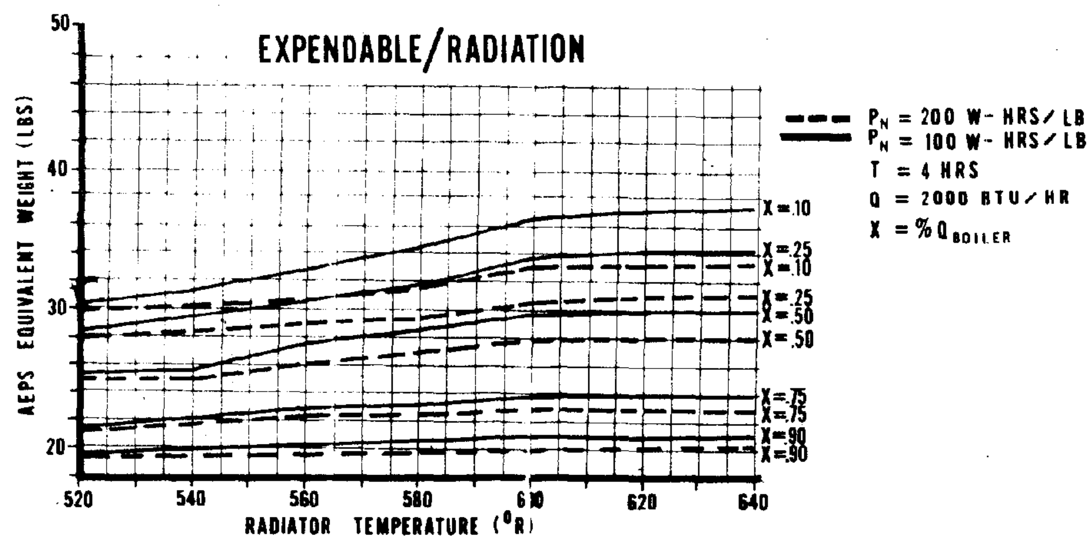

EXPENDABLE/RADIATION
Q = 2500 BTU/HR
X = % Q BOILER
VEHICLE EQUIVALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)
X = .90
X = .75
X = .50
X = .25
X = .10

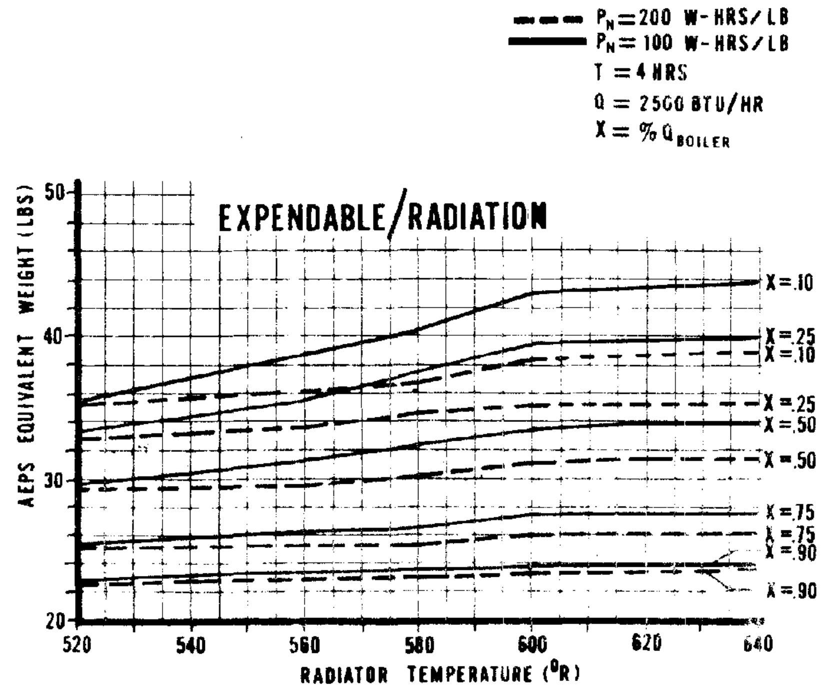

EXPENDABLE/RADIATION
AEPS Equivalent Volume (in³)
Radiator Temperature (°R)
X=.1
X=.25
X=.75
X=.90
X=.50

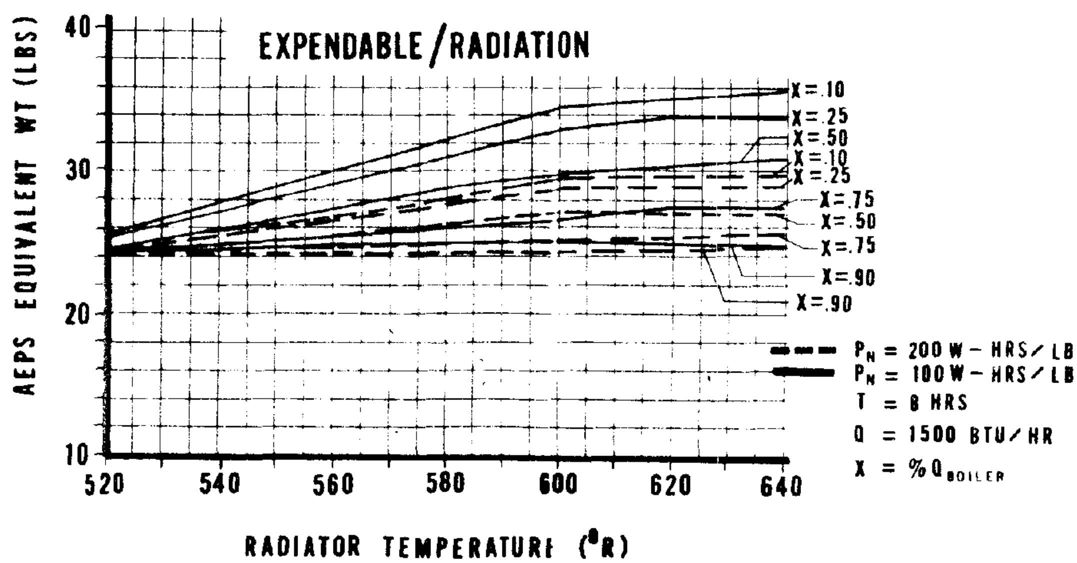

EXPENDABLE/RADIATION
AEPS Equivalent Volume (in^3)
Radiator Temperature (°R)
Q = 2000 BTU/HR
X = % Q_{BOILER}
T = 8HRS
X=.1
X=.25
X=.50
X=.75
X=.90

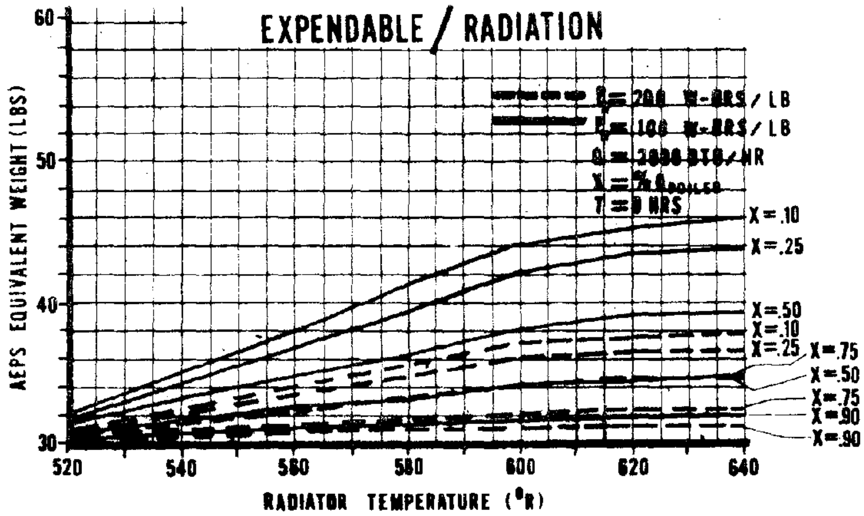

EXPENDABLE/RADIATION
AEPS Equivalent Volume (in^3)
Radiator Temperature (°R)
Q = 2500 BTU/HR
X = % Q_{BOILER}
T = 8HRS
X=.1
X=.25
X=.50
X=.75
X=.90


EXPENDABLE/RADIATION
AEPS EQUIVALENT WT (LBS)
30
20
10
0
520
540
560
580
600
620
640
RADIATOR TEMPERATURE (°R)
X = .10
X = .25
X = .10
X = .25
X = .50
X = .50
X = .75
X = .75
X = .90 X = .90
P_N = 200 W-HRS/LB
P_N = 100 W-HRS/LB
T = 4 HRS
Q = 1500 BTU/HR
X = % Q_BOILER

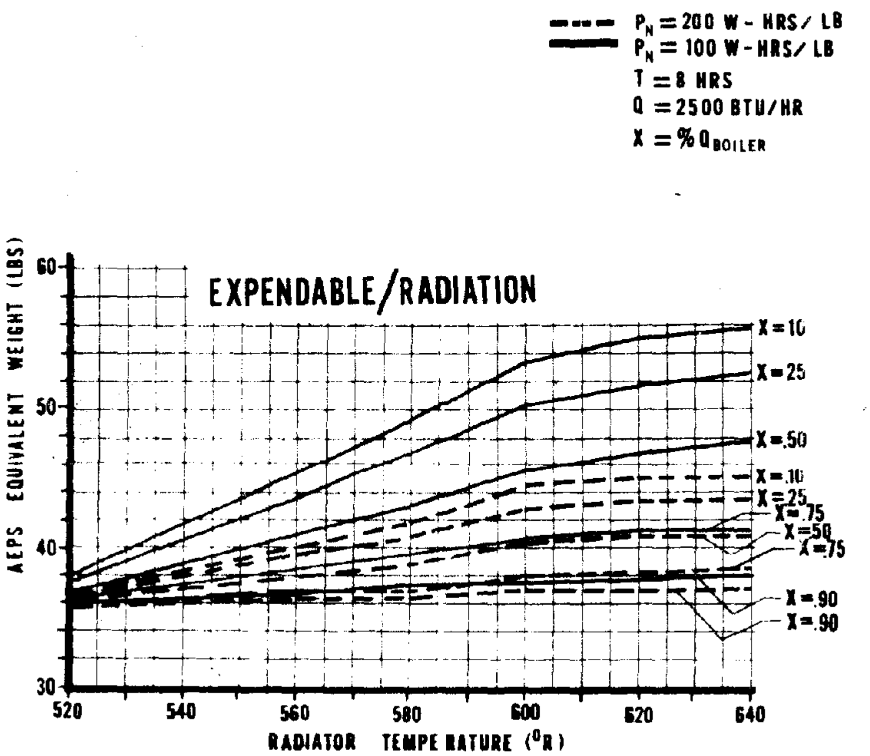

EXPENDABLE/RADIATION
AEPS EQUIVALENT WEIGHT (LBS)
50
40
30
20
520
540
560
580
600
620
640
RADIATOR TEMPERATURE (°R)
X = .10
X = .25
X = .10
X = .25
X = .50
X = .50
X = .75
X = .75
X = .90
X = .90
P_N = 200 W-HRS/LB
P_N = 100 W-HRS/LB
T = 4 HRS
Q = 2000 BTU/HR
X = % Q_BOILER


P_N=200 W-HRS/LB
P_N=100 W-HRS/LB
T =4 HRS
Q = 2500 BTU/HR
X= % Q BOILER
EXPENDABLE/RADIATION
AEPS EQUIVALENT WEIGHT (LBS)
RADIATOR TEMPERATURE (°R)
X=.10
X=.25
X=.10
X=.25
X=.50
X=.50
X=.75
X=.75
X=.90
X=.90


EXPENDABLE/RADIATION
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)
X=.10
X=.25
X=.50
X=.10
X=.25
X=.75
X=.50
X=.75
X=.90
X=.90
P_N = 200 W - HRS/LB
P_N = 100 W - HRS/LB
T = 8 HRS
Q = 1500 BTU/HR
X = % Q BOILER



EXPENDABLE / RADIATION
AEPS EQUIVALENT WEIGHT (LBS)
RADIATOR TEMPERATURE (°R)
60
50
40
30
520
540
560
580
600
620
640
X = .10
X = .25
X = .50
X = .10
X = .25
X = .75
X = .50
X = .75
X = .90
X = .90



P_N = 200 W - HRS / LB
P_N = 100 W - HRS / LB
T = 8 HRS
Q = 2500 BTU/HR
X = % Q_{BOILER}
EXPENDABLE/RADIATION
AEPS EQUIVALENT WEIGHT (LBS)
RADIATOR TEMPERATURE (°R)
60
50
40
30
520
540
560
580
600
620
640
X = .10
X = .25
X = .50
X = .10
X = .25
X = .75
X = .50
X = .75
X = .90
X = .90

CONCEPT 14 - EXPENDABLE/THERMAL STORAGE (ICE)

This hybrid concept consists of a thermal storage unit and the water boiler in parallel and connected by the LCG temperature control valve. The TCV selects the percentage of LCG heat load shared by each subsystem. The water boiler provides temperature control for the vent loop. Vent loop humidity control is provided by condensation of the water vapor in the H_2O boiler and removal of the condensate by the water separator. The condensate is fed to the water boiler to provide additional cooling capacity. As is the case in the ice thermal storage unit concept, it may be required to add an intermediate coolant loop to prevent LCG freeze-up. Regeneration requires a vehicle refrigeration system.

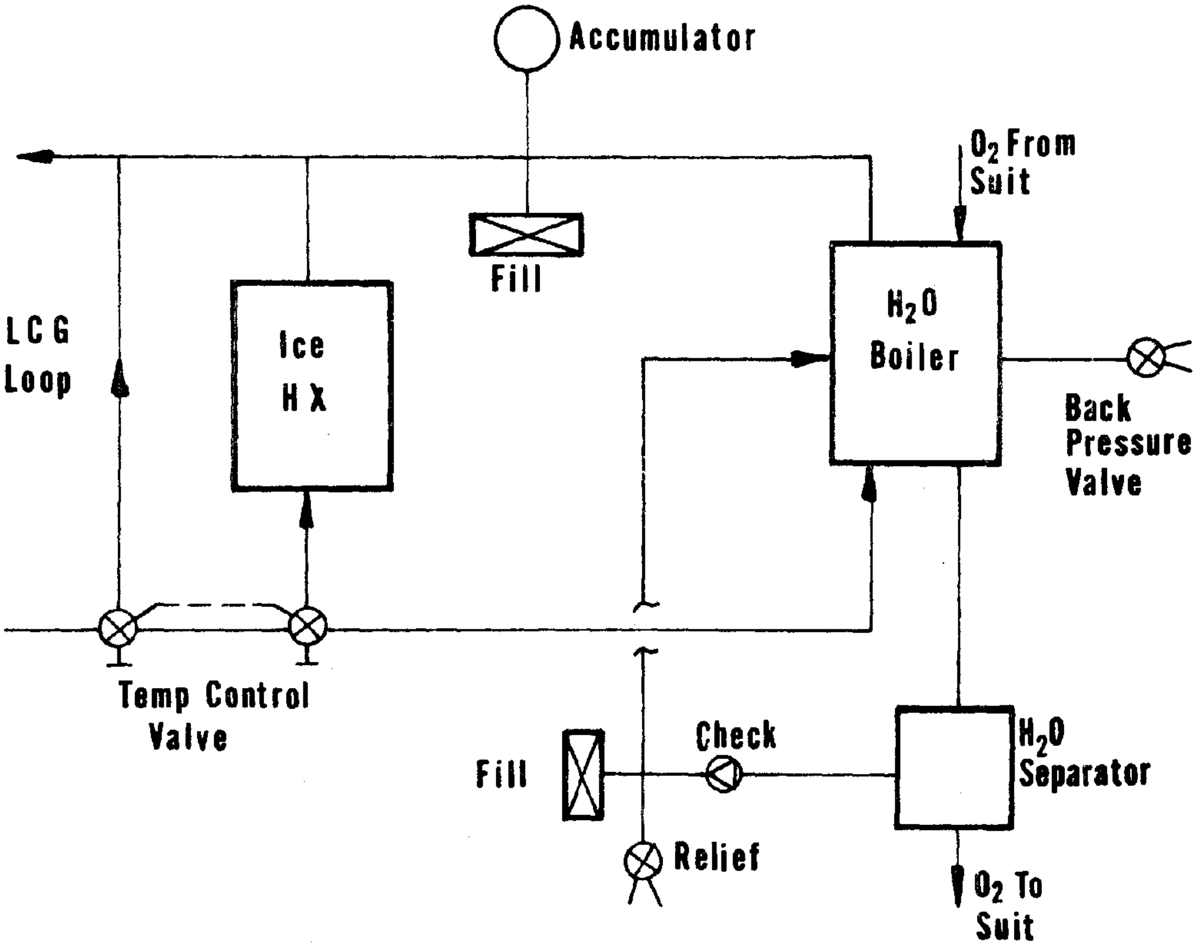
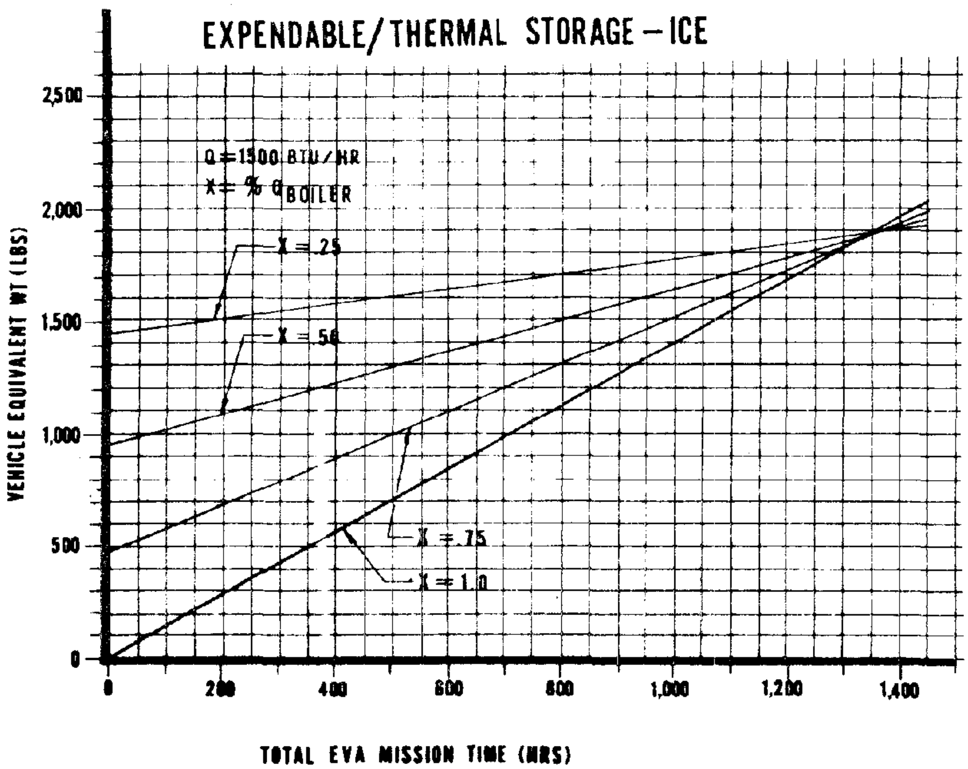
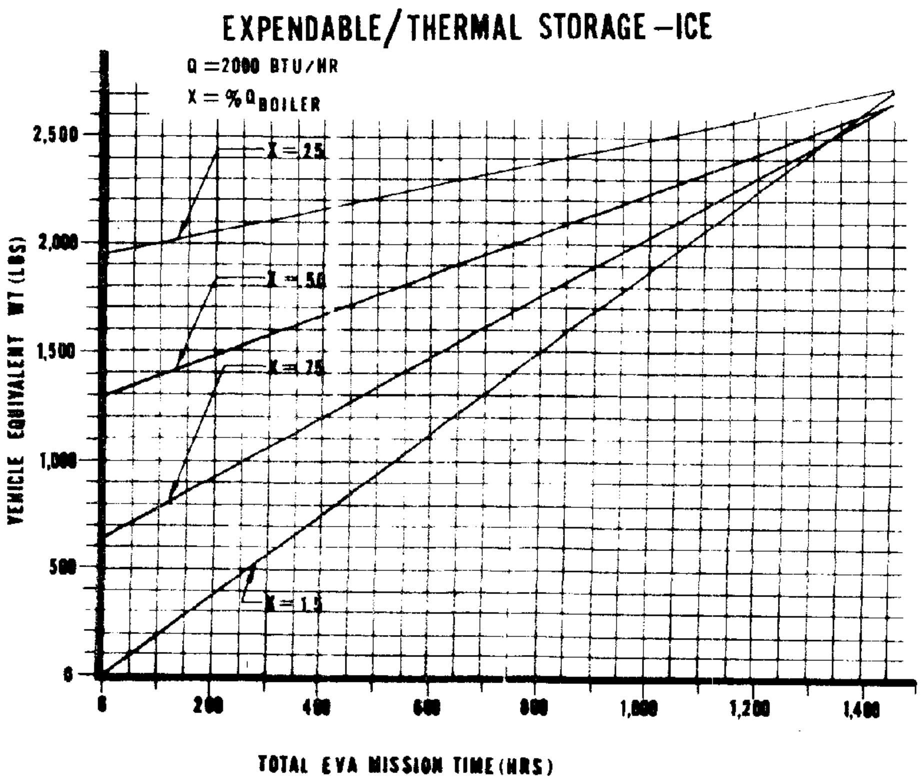
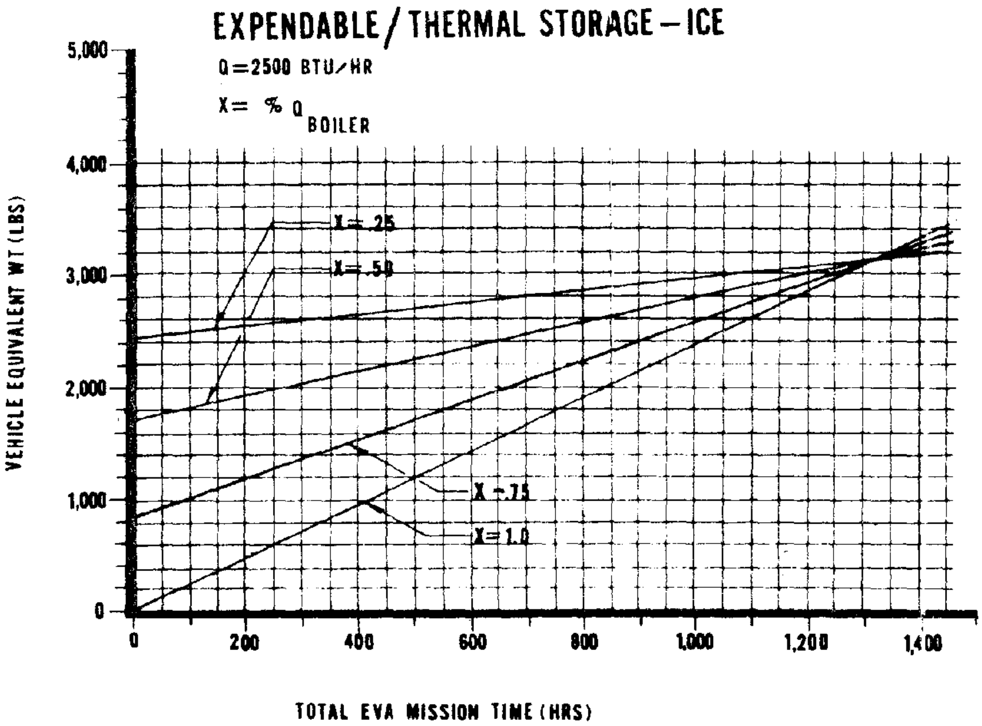
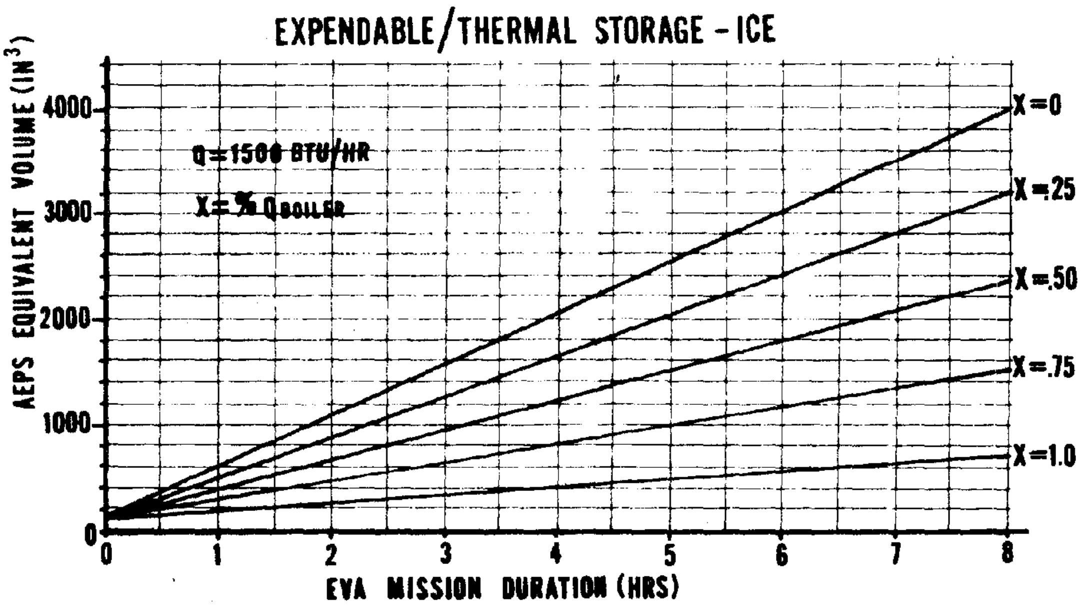


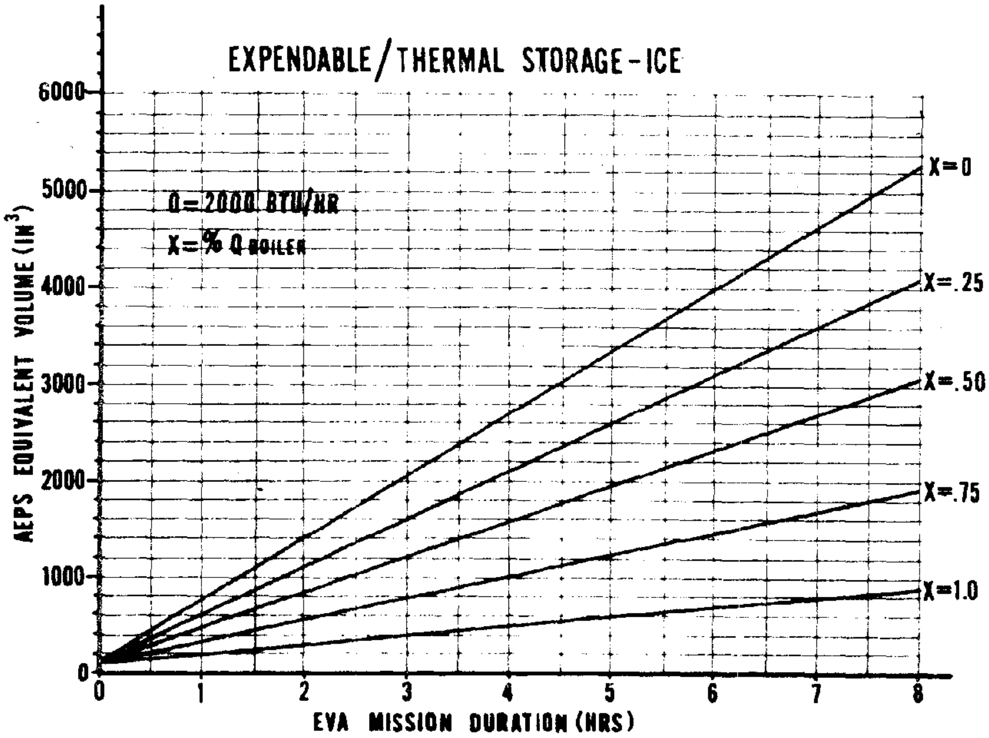
FIGURE 4-14. EXPENDABLE/THERMAL STORAGE - ICE

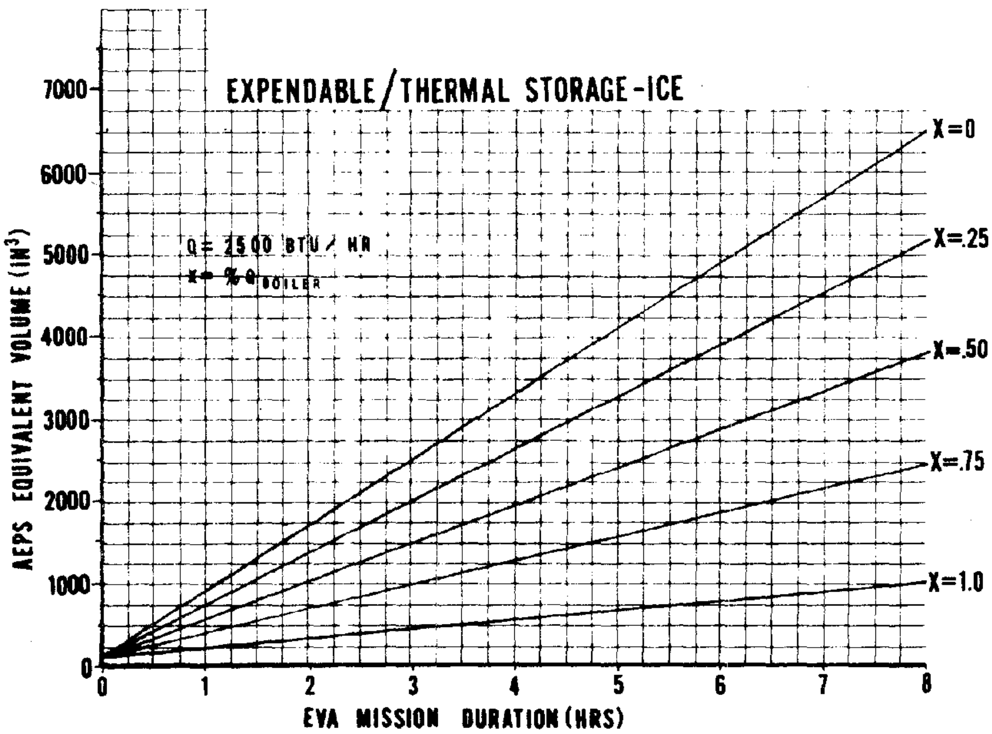

EXPENDABLE/THERMAL STORAGE – ICE
Q = 1500 BTU/HR
X = % Q BOILER
X = .25
X = .50
X = .75
X = 1.0
VEHICLE EQUIVALENT WT (LBS)
0
500
1,000
1,500
2,000
2,500
0
200
400
600
800
1,000
1,200
1,400
TOTAL EVA MISSION TIME (HRS)

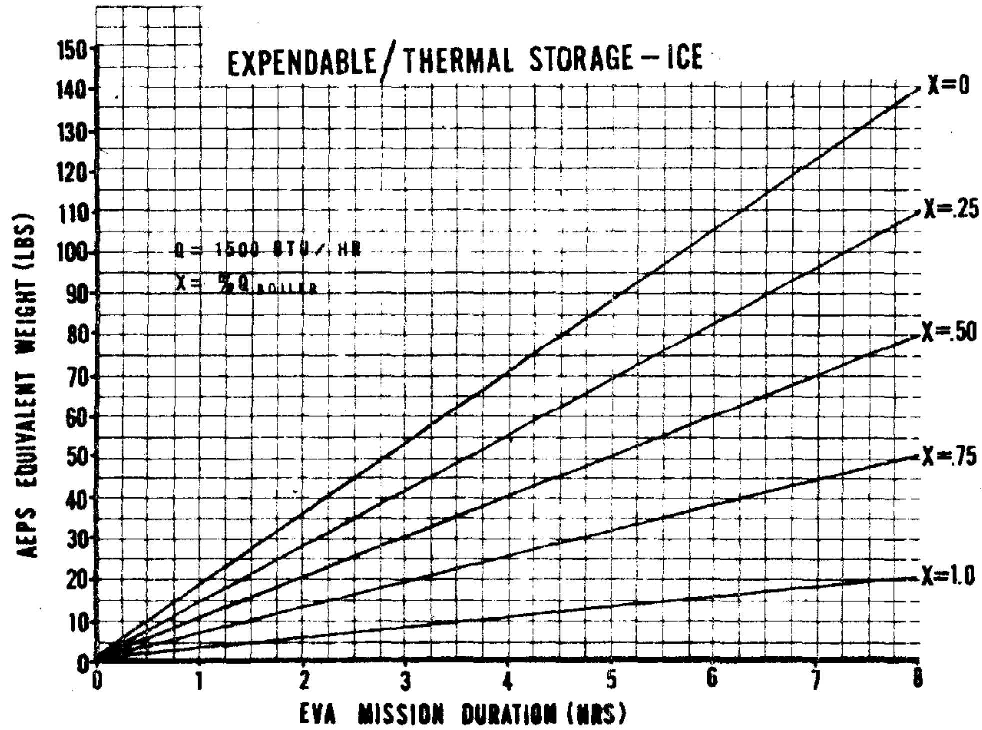

EXPENDABLE/THERMAL STORAGE – ICE
Q = 2000 BTU/HR
X = % Q BOILER
X = .25
X = .50
X = .75
X = 1.0
VEHICLE EQUIVALENT WT (LBS)
0
500
1,000
1,500
2,000
2,500
0
200
400
600
800
1,000
1,200
1,400
TOTAL EVA MISSION TIME (HRS)

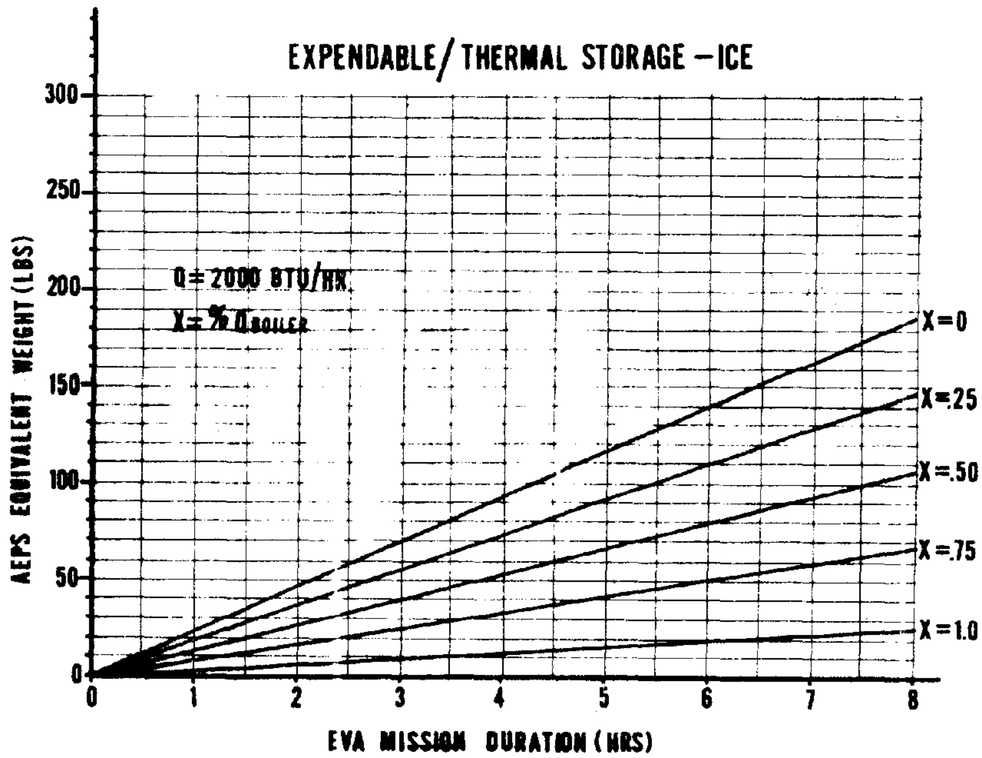

EXPENDABLE/THERMAL STORAGE – ICE
Q=2500 BTU/HR
X= % Q BOILER
X=.25
X=.50
X=.75
X=1.0
VEHICLE EQUIVALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)
5,000
4,000
3,000
2,000
1,000
0
200
400
600
800
1,000
1,200
1,400

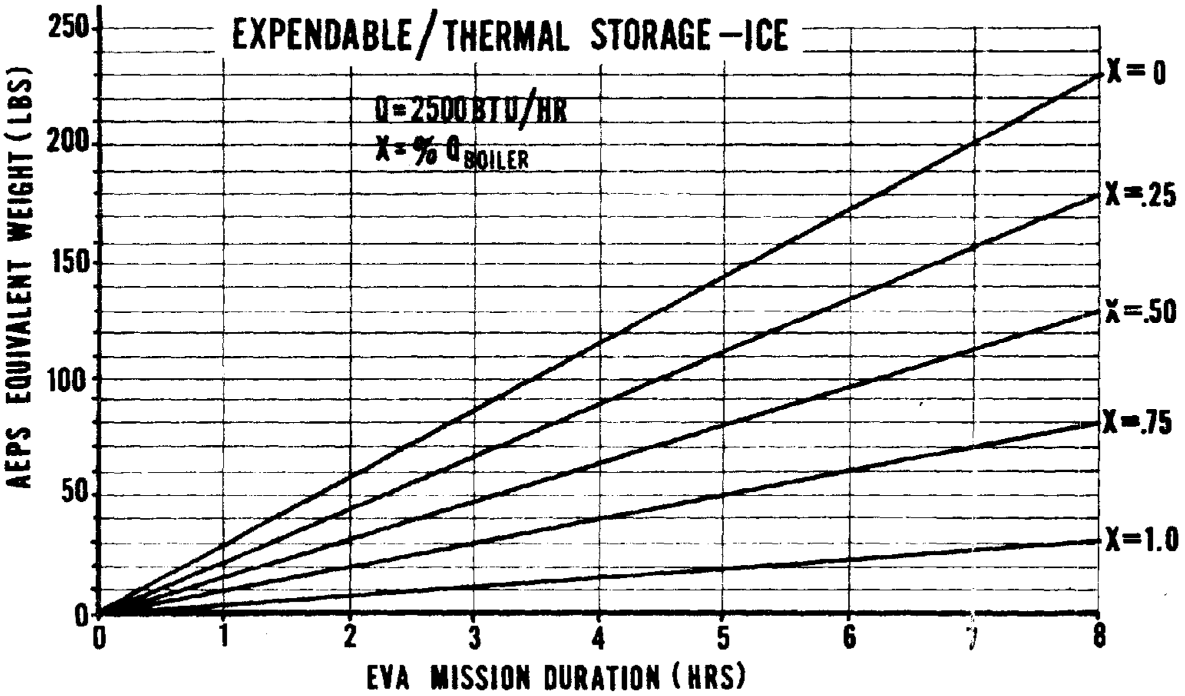

EXPENDABLE/THERMAL STORAGE – ICE
Q=1500 BTU/HR
X=% Q BOILER
X=0
X=.25
X=.50
X=.75
X=1.0
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8


EXPENDABLE/THERMAL STORAGE-ICE
Q=2000 BTU/HR
X=% Q BOILER
X=0
X=.25
X=.50
X=.75
X=1.0
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)
0
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8


EXPENDABLE/THERMAL STORAGE-ICE
Q=2500 BTU/HR
X=% Q BOILER
X=0
X=.25
X=.50
X=.75
X=1.0
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)
0
1000
2000
3000
4000
5000
6000
7000
1
2
3
4
5
6
7
8


EXPENDABLE/THERMAL STORAGE – ICE
Q = 1500 BTU/HR
X = %Q BOILER
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
X=0
X=.25
X=.50
X=.75
X=1.0


EXPENDABLE/THERMAL STORAGE – ICE
Q = 2000 BTU/HR
X = %Q BOILER
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
X=0
X=.25
X=.50
X=.75
X=1.0


EXPENDABLE/THERMAL STORAGE – ICE
Q = 2500 BTU/HR
X = % Q BOILER
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
X = 0
X = .25
X = .50
X = .75
X = 1.0
0
50
100
150
200
250
0
1
2
3
4
5
6
7
8

CONCEPT 15 - EXPENDABLE/THERMAL STORAGE (PH_4Cl)

This hybrid concept utilizes a water boiler in parallel with a PH_4Cl thermal storage unit via an LCG temperature control valve. The temperature control valve selects what percentage of the heat load from the LCG is shared by each subsystem, the intention being that the PH_4Cl thermal storage unit handles the average heat load and the water boiler handles peak loads. By doing this, compressor power and expendable water are minimized.

The water boiler provides humidity control by cooling the vent loop which feeds the separated water to the boiler via the water separator to provide additional cooling capacity. A variable speed compressor and variable expansion valve are utilized in the thermal storage subsystem to prevent over-cooling under low or no load conditions. This system is flexible in that it can be sized for a multitude of thermal load sharing combinations. As is the case in the PH_4Cl thermal storage concept, research and development is required on PH_4Cl and its thermal storage unit configuration.

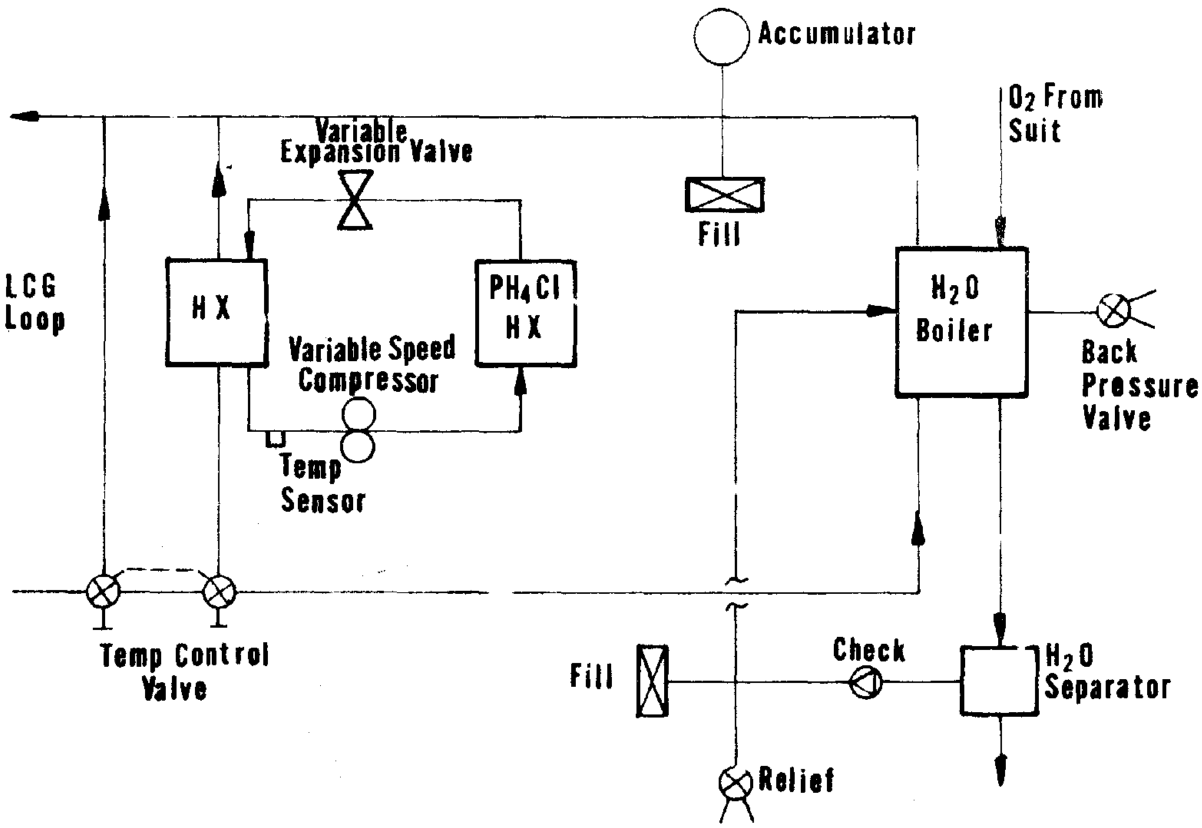
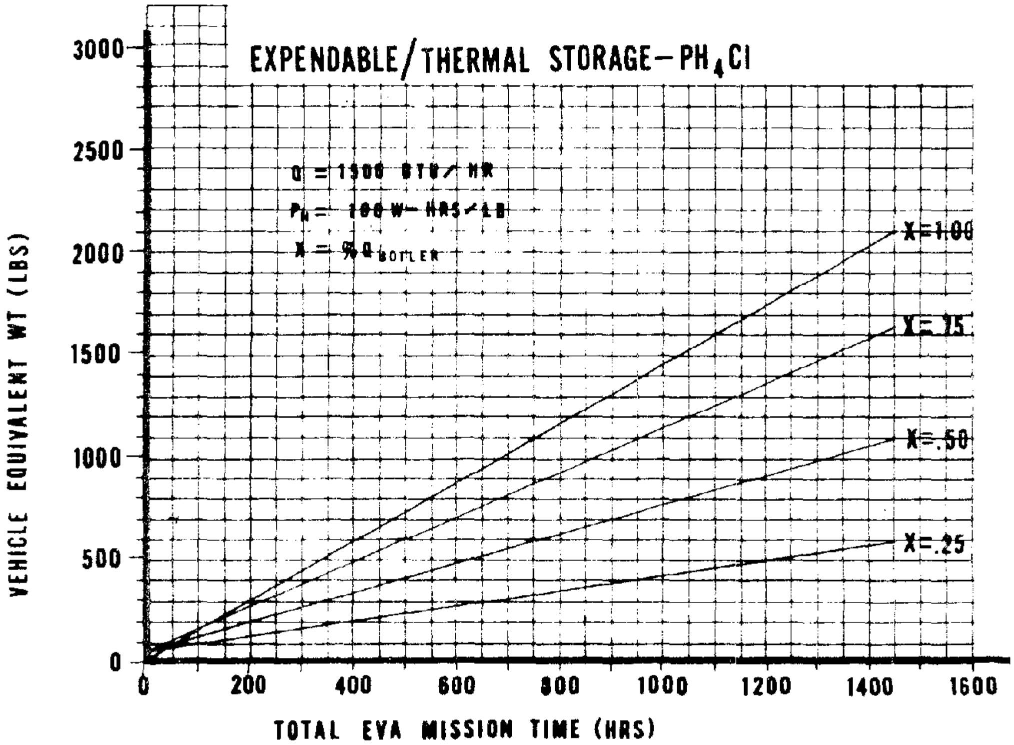
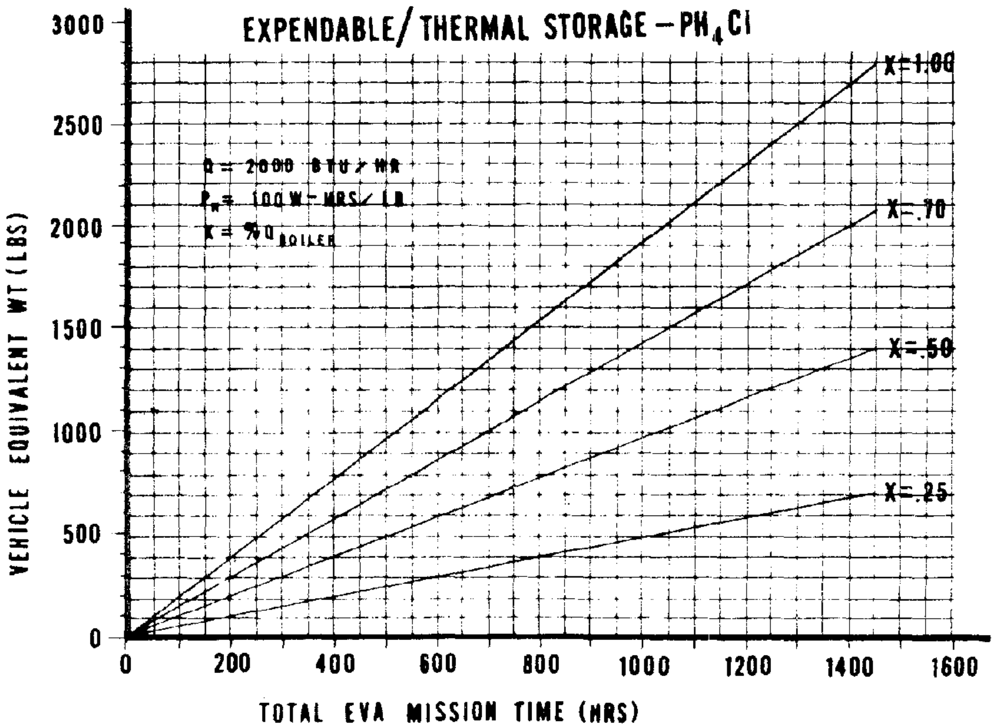
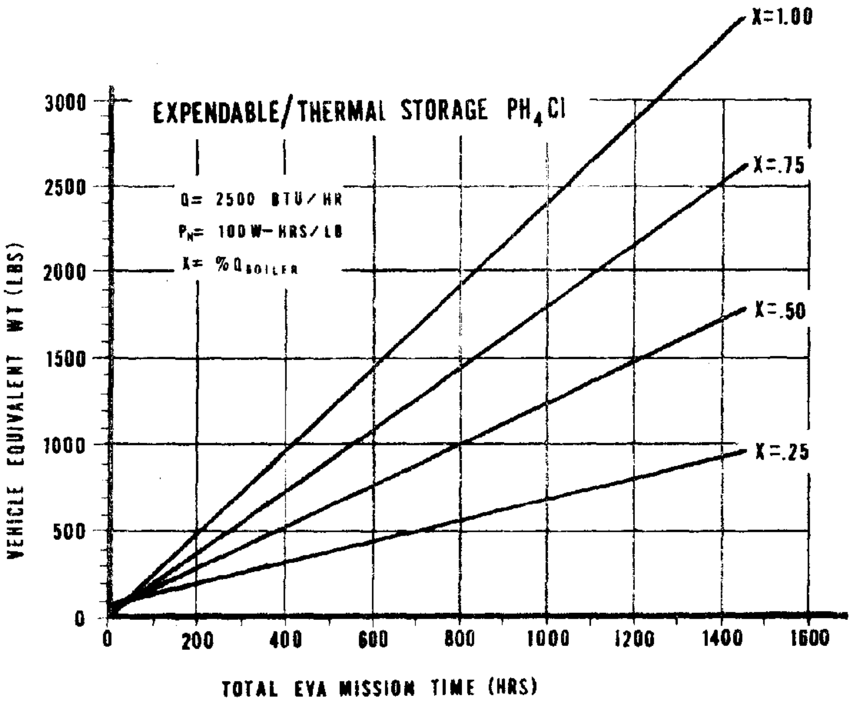
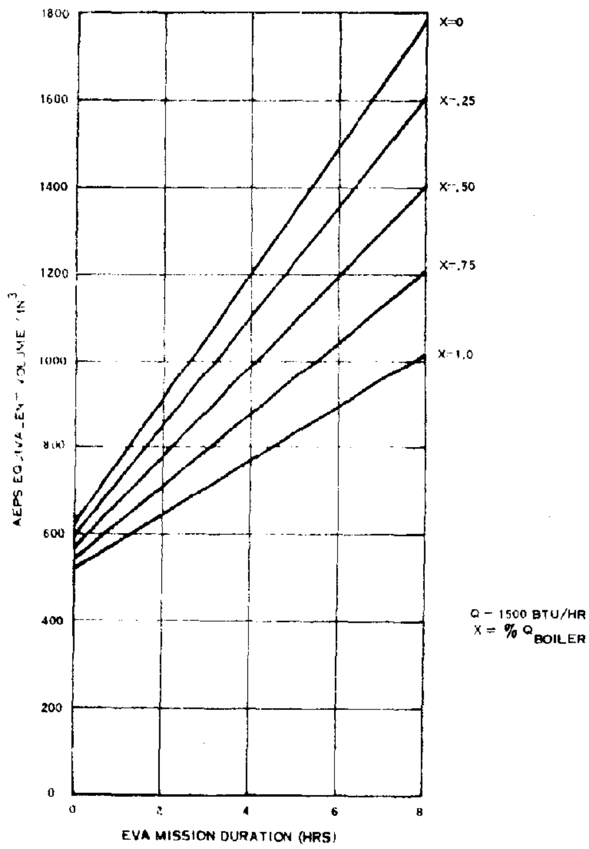


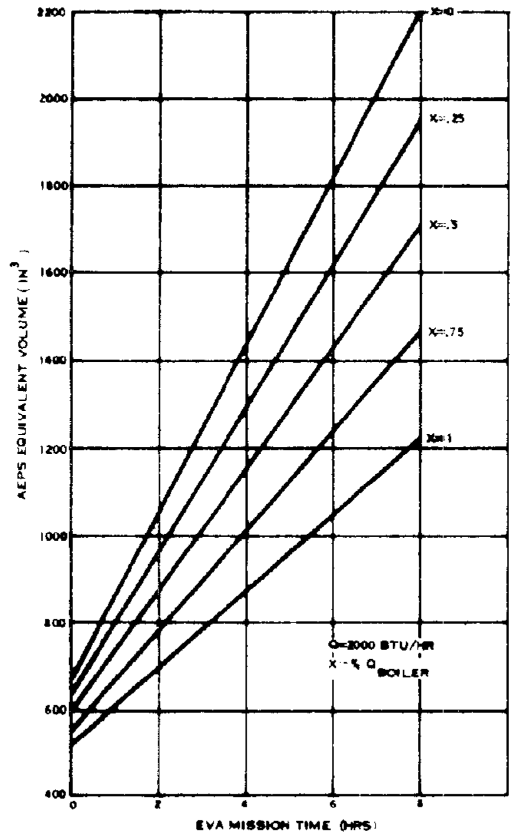
FIGURE 4–15. EXPENDABLE/THERMAL STORAGE – PH_4Cl


EXPENDABLE/THERMAL STORAGE-PH_4Cl
Q = 1500 BTU/HR
P_W = 100 W-HRS/LB
X = %Q BOILER
X=1.00
X=.75
X=.50
X=.25
VEHICLE EQUIVALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)
0
500
1000
1500
2000
2500
3000
200
400
600
800
1000
1200
1400
1600

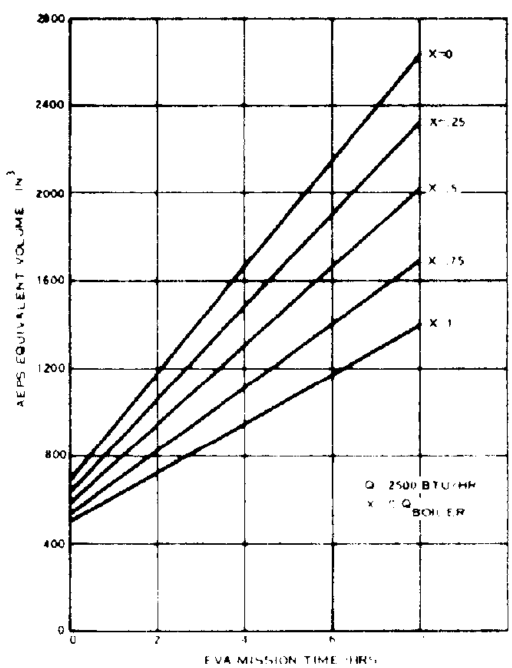

EXPENDABLE/THERMAL STORAGE-PH_4Cl
Q = 2000 BTU/HR
P_W = 100 W-HRS/LB
X = %Q BOILER
X=1.00
X=.70
X=.50
X=.25
VEHICLE EQUIVALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)
0
500
1000
1500
2000
2500
3000
200
400
600
800
1000
1200
1400
1600


EXPENDABLE/THERMAL STORAGE PH_4Cl
Q= 2500 BTU/HR
P_N= 100 W-HRS/LB
X= % Q_{BOILER}
X=1.00
X=.75
X=.50
X=.25
VEHICLE EQUIVALENT WT (LBS)
TOTAL EVA MISSION TIME (HRS)
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
1600

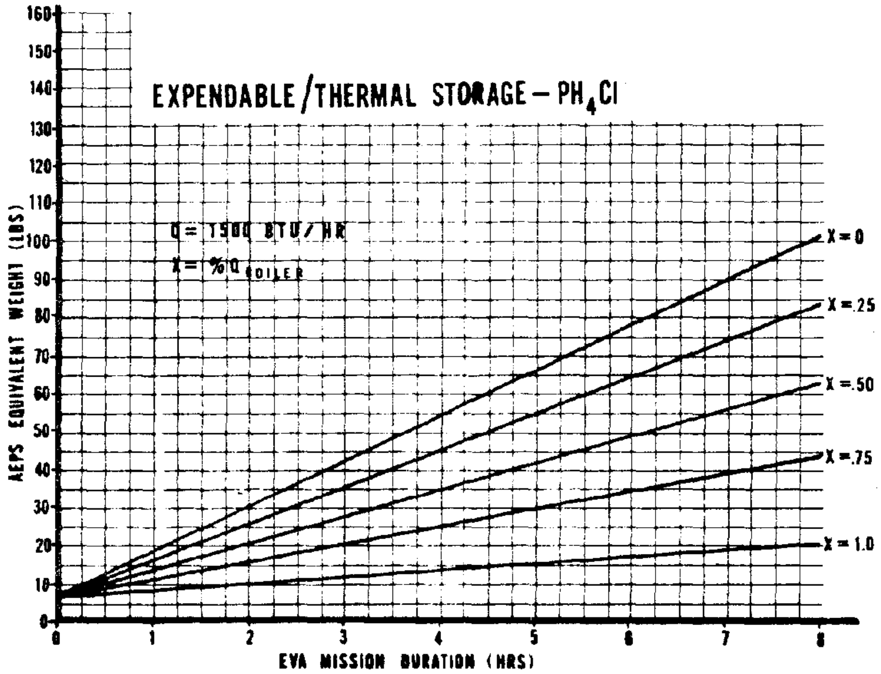

X=0
X=.25
X=.50
X=.75
X=1.0
Q = 1500 BTU/HR
X = % Q_{BOILER}
EVA MISSION DURATION (HRS)
1800
1600
1400
1200
1000
600
400
200
0
0
4
6
8

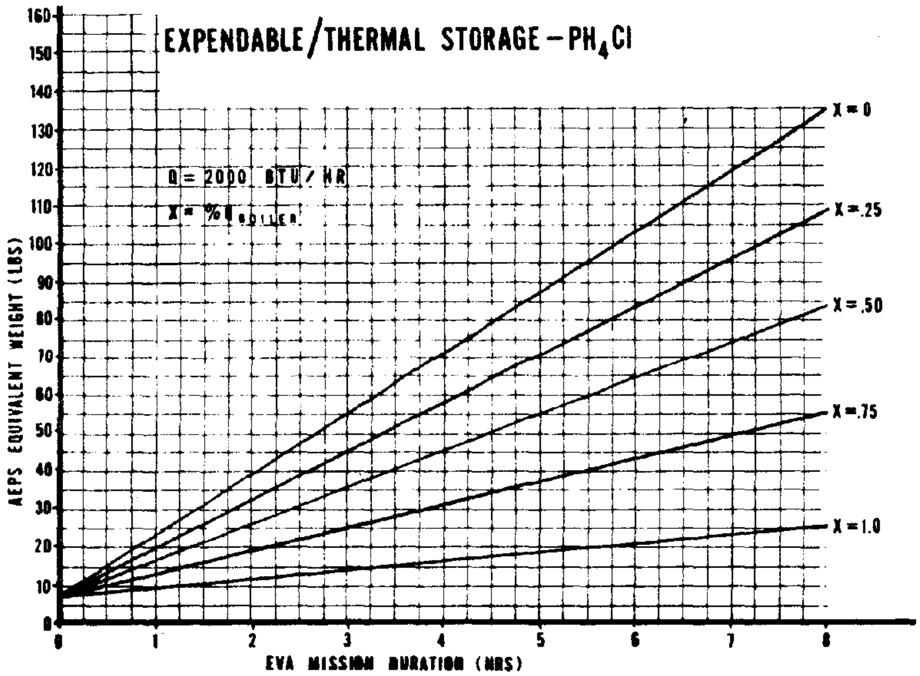


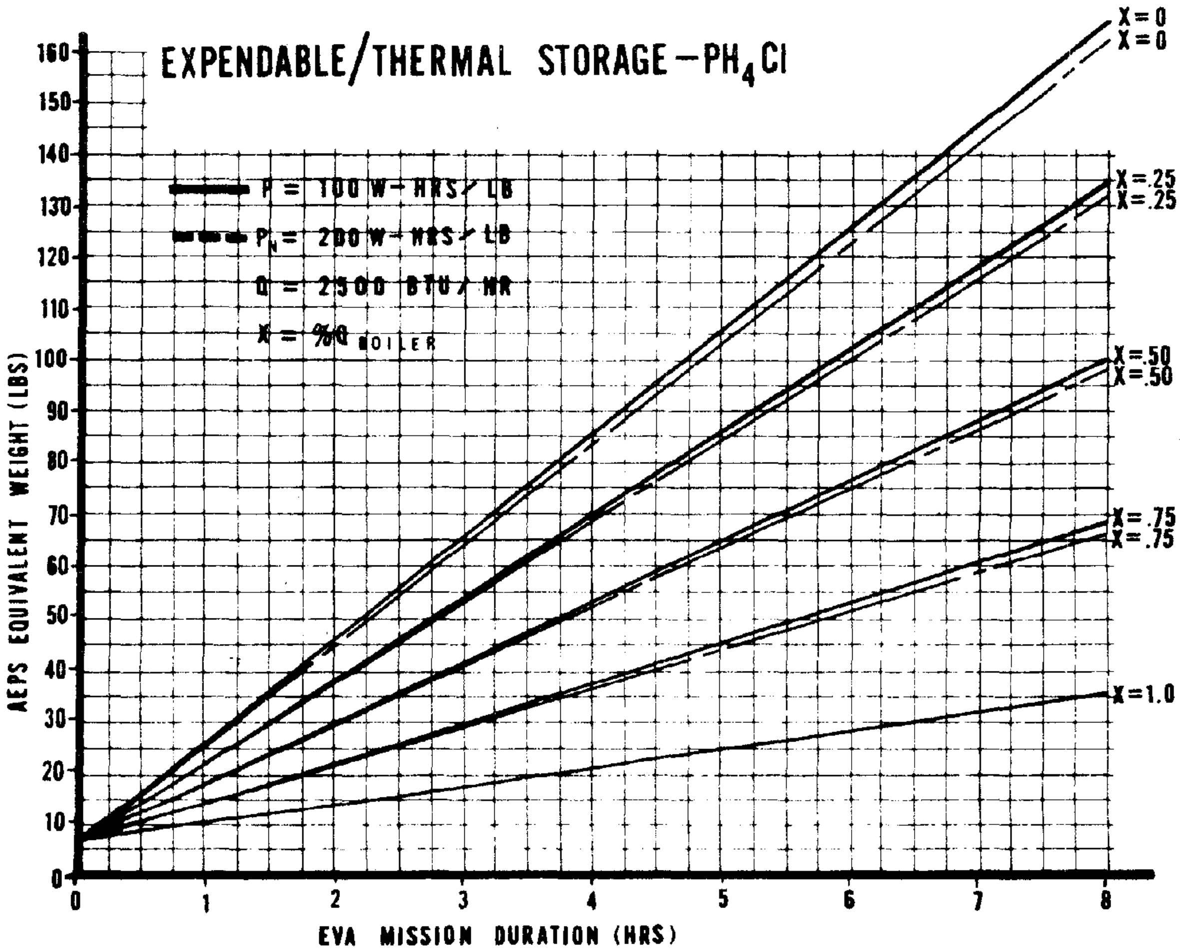
EXPENDABLE/THERMAL STORAGE – PH_4Cl



EXPENDABLE/THERMAL STORAGE – PH_4Cl


EXPENDABLE/THERMAL STORAGE – PH_4Cl
Q = 1500 BTU/HR
X = %Q BOILER
X = 0
X = .25
X = .50
X = .75
X = 1.0
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0
1
2
3
4
5
6
7
8


EXPENDABLE/THERMAL STORAGE – PH_4Cl
Q = 2000 BTU/HR
X = %Q BOILER
X = 0
X = .25
X = .50
X = .75
X = 1.0
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0
1
2
3
4
5
6
7
8


EXPENDABLE/THERMAL STORAGE—PH4Cl
P = 100 W-HRS/LB
PN = 200 W-HRS/LB
Q = 2500 BTU/HR
X = %Q BOILER
X = 0
X = 0
X = .25
X = .25
X = .50
X = .50
X = .75
X = .75
X = 1.0
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0
1
2
3
4
5
6
7
8

CONCEPT 16 - RADIATION/THERMAL STORAGE (ICE)

This hybrid concept places a radiation/vapor compression system in series with an ice thermal storage unit. The thermal storage unit removes heat from the LCG and vent loops by the heat of fusion of ice. A portion of the total heat load is transferred from the thermal storage unit to the radiator by the vapor compression cycle. A trade-off may be made between radiator size and thermal storage unit weight. It can be seen that the radiator is not sized for AEPS maximum heat load, but rather a portion of the average load. For low load conditions at the beginning of the mission, it is necessary to have a variable speed compressor and variable expansion valve to prevent subcooling the thermal storage unit. This may also be overcome by not starting the vapor compression system at the beginning of the mission.

Regeneration of the thermal storage unit may be achieved in the vehicle by a vehicle refrigeration system or outside the vehicle by the system radiator and vapor compression cycle. This may be accomplished by turning on the compressor and rejecting the heat of fusion of ice from the thermal storage unit via the radiator to deep space.

The TCV provides automatic LCG temperature control. Vent loop humidity control is achieved by condensation of the water vapor in the thermal storage unit and separation and removal of the condensate in the water separator and holding tank. Because of its size, this concept is not applicable to back mounting and is, therefore, eliminated from consideration for Space Station applications.

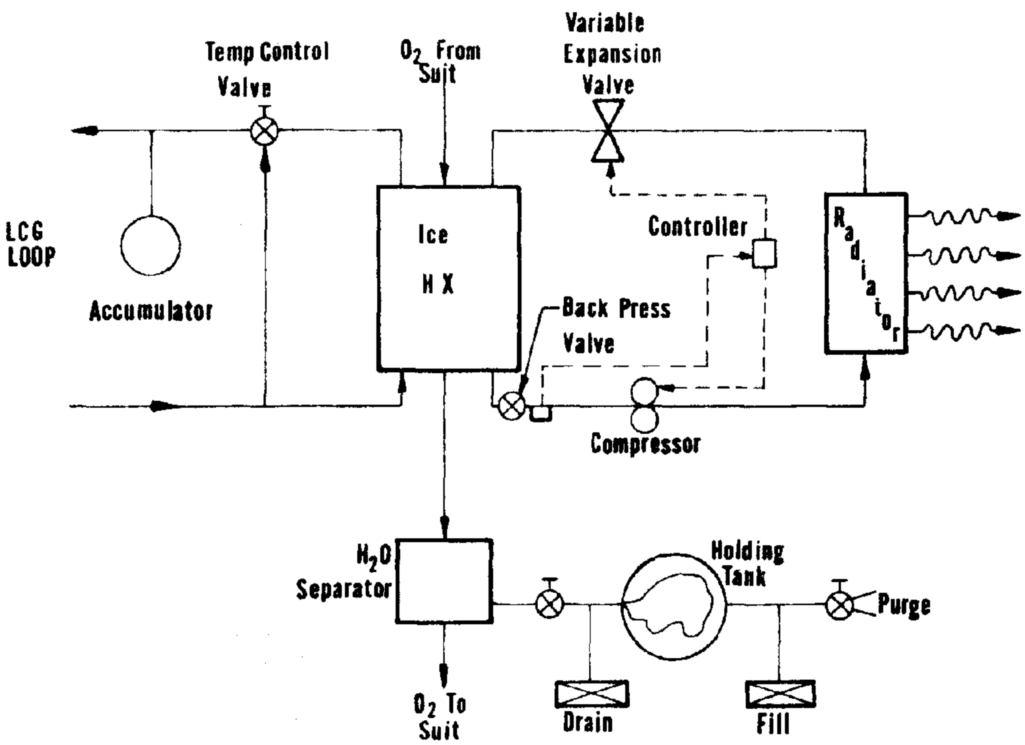
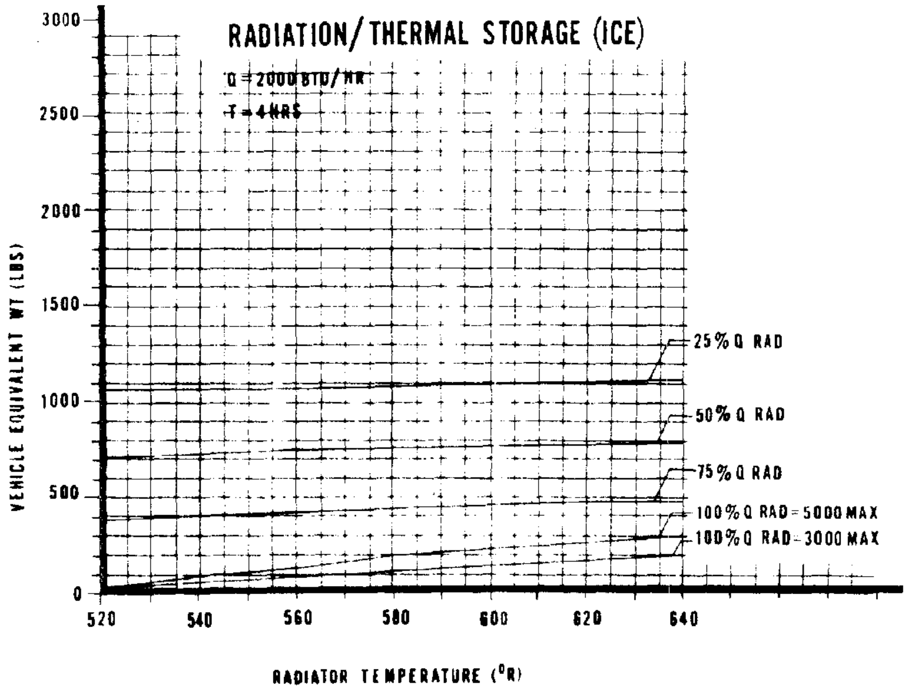
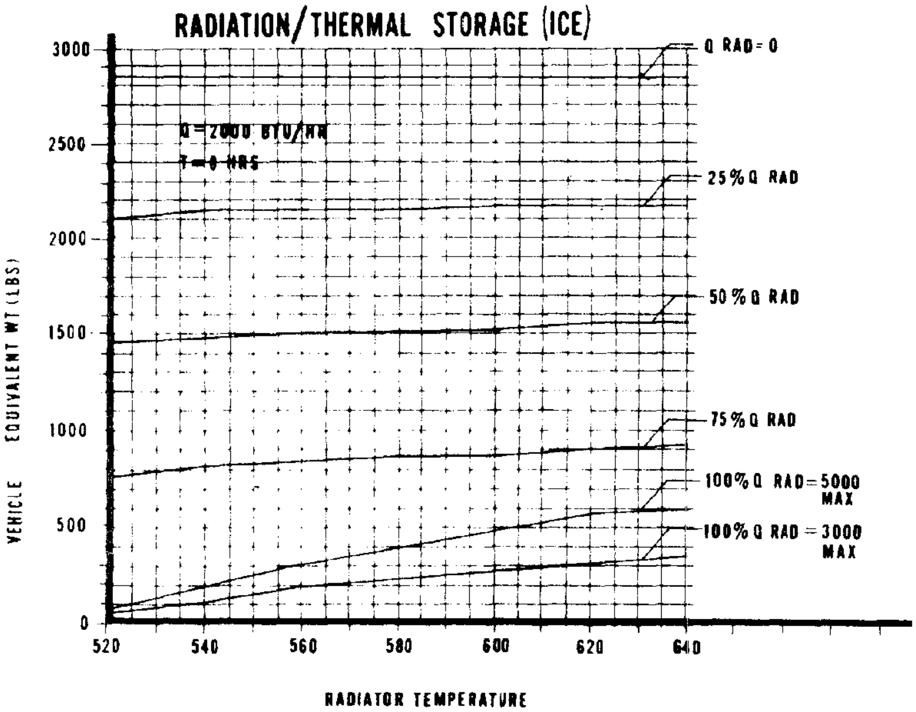
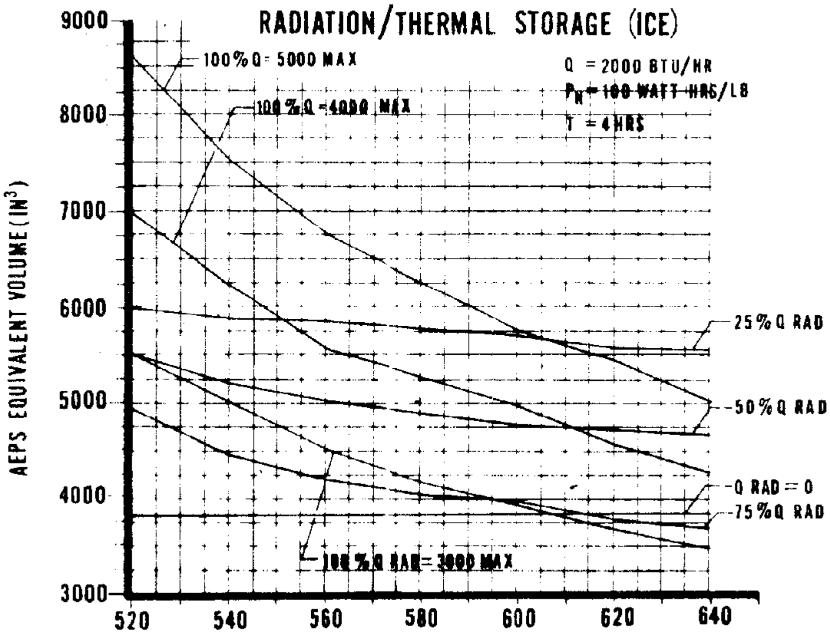


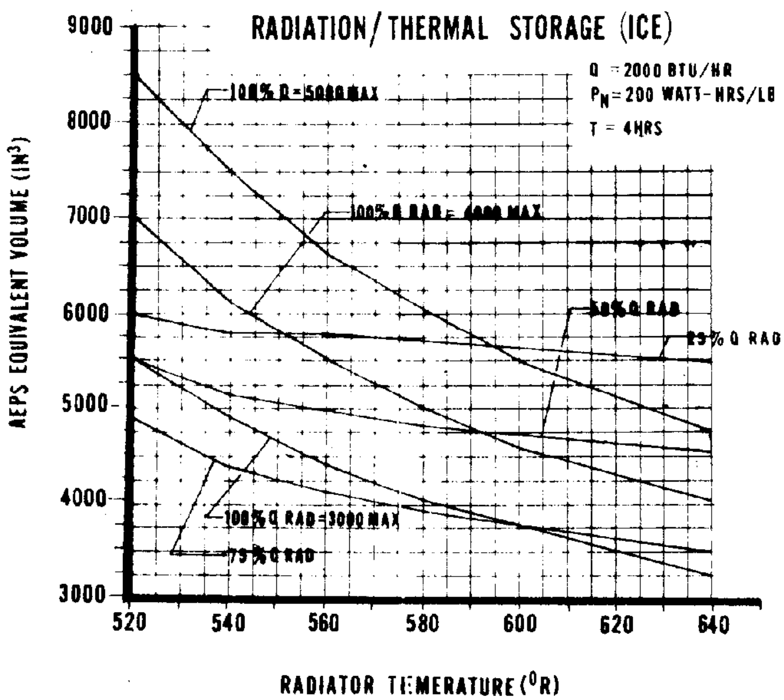
FIGURE 4–16. RADIATION/THERMAL STORAGE – ICE


RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
T = 4 HRS
25% Q RAD
50% Q RAD
75% Q RAD
100% Q RAD = 5000 MAX
100% Q RAD = 3000 MAX
VEHICLE EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)
0
500
1000
1500
2000
2500
3000
520
540
560
580
600
620
640

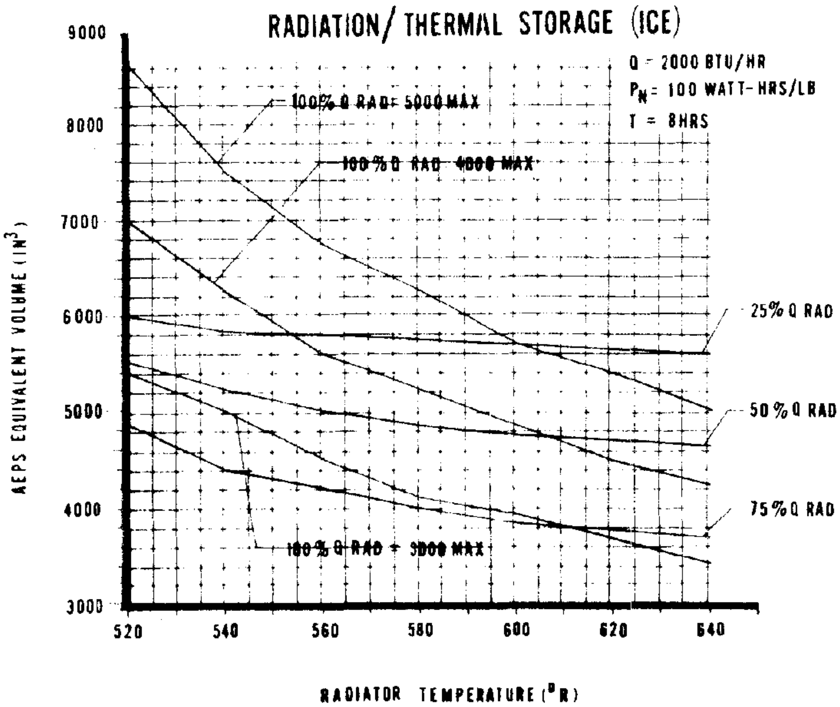

RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
T = 8 HRS
Q RAD = 0
25% Q RAD
50% Q RAD
75% Q RAD
100% Q RAD = 5000 MAX
100% Q RAD = 3000 MAX
VEHICLE EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE
0
500
1000
1500
2000
2500
3000
520
540
560
580
600
620
640

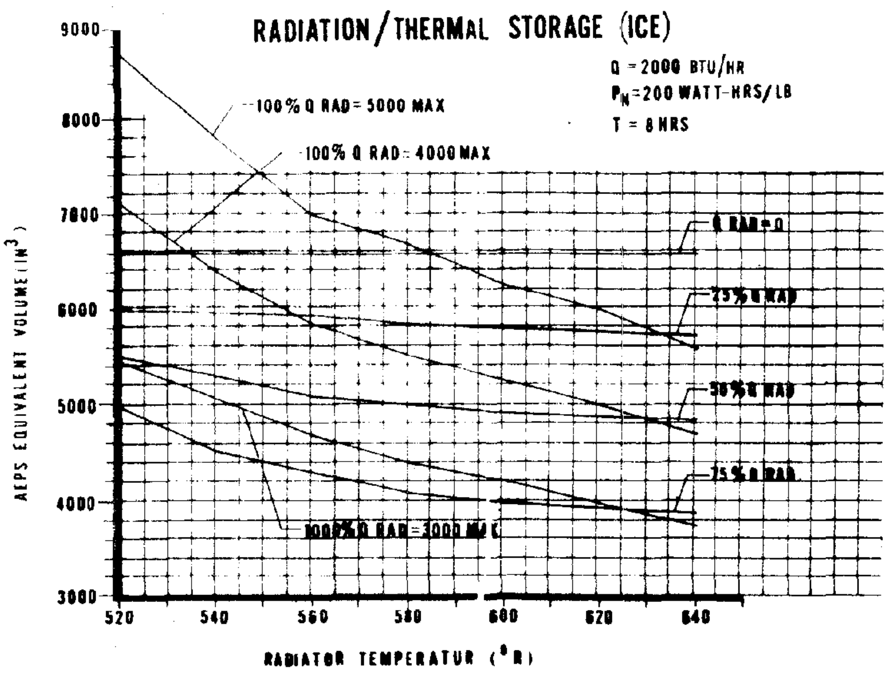


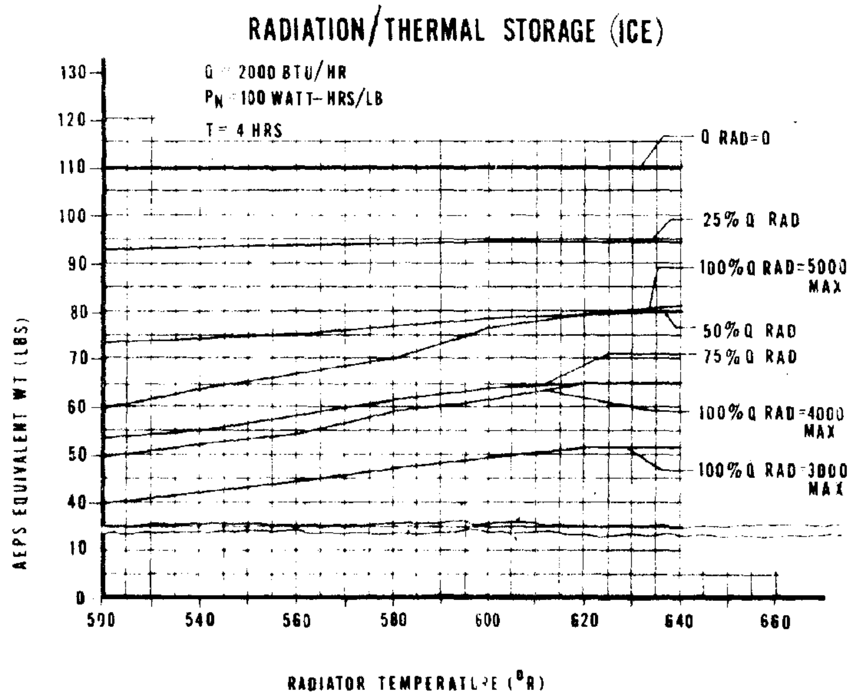
RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N = 100 WATT-HRS/LB
T = 4 HRS
100% Q = 5000 MAX
100% Q = 4000 MAX
25% Q RAD
50% Q RAD
Q RAD = 0
75% Q RAD
100% Q RAD = 3000 MAX
AEPS EQUIVALENT VOLUME (IN³)
9000
8000
7000
6000
5000
4000
3000
520
540
560
580
600
620
640



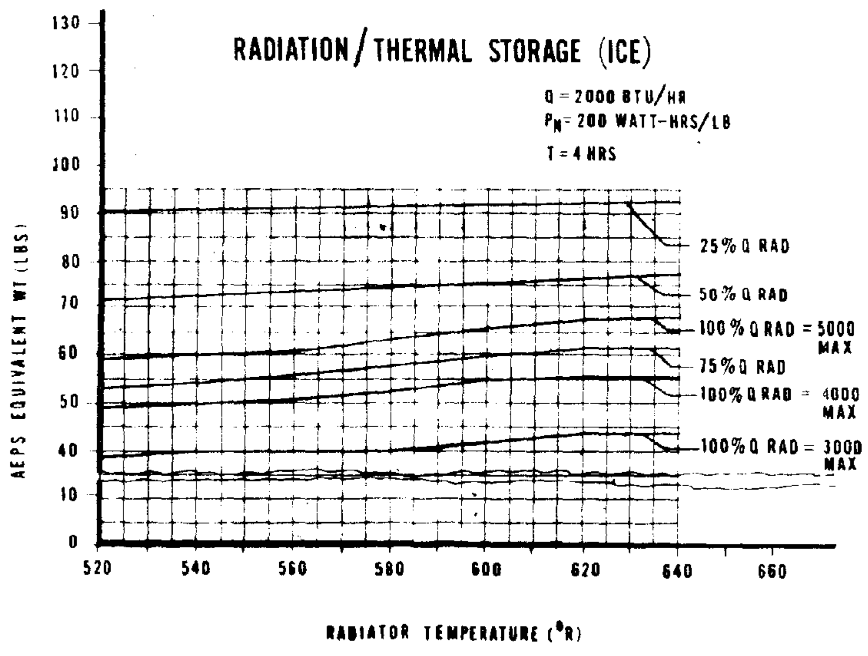
RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N = 200 WATT-HRS/LB
T = 4 HRS
100% Q = 5000 MAX
100% Q RAD = 4000 MAX
50% Q RAD
25% Q RAD
100% Q RAD = 3000 MAX
75% Q RAD
AEPS EQUIVALENT VOLUME (IN³)
9000
8000
7000
6000
5000
4000
3000
520
540
560
580
600
620
640
RADIATOR TEMERATURE (°R)


RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N = 100 WATT-HRS/LB
T = 8HRS
100% Q RAD = 5000 MAX
100% Q RAD 4000 MAX
100% Q RAD = 3000 MAX
25% Q RAD
50% Q RAD
75% Q RAD
AEPS EQUIVALENT VOLUME (IN³)
RADIATOR TEMPERATURE (°R)
9000
8000
7000
6000
5000
4000
3000
520
540
560
580
600
620
640

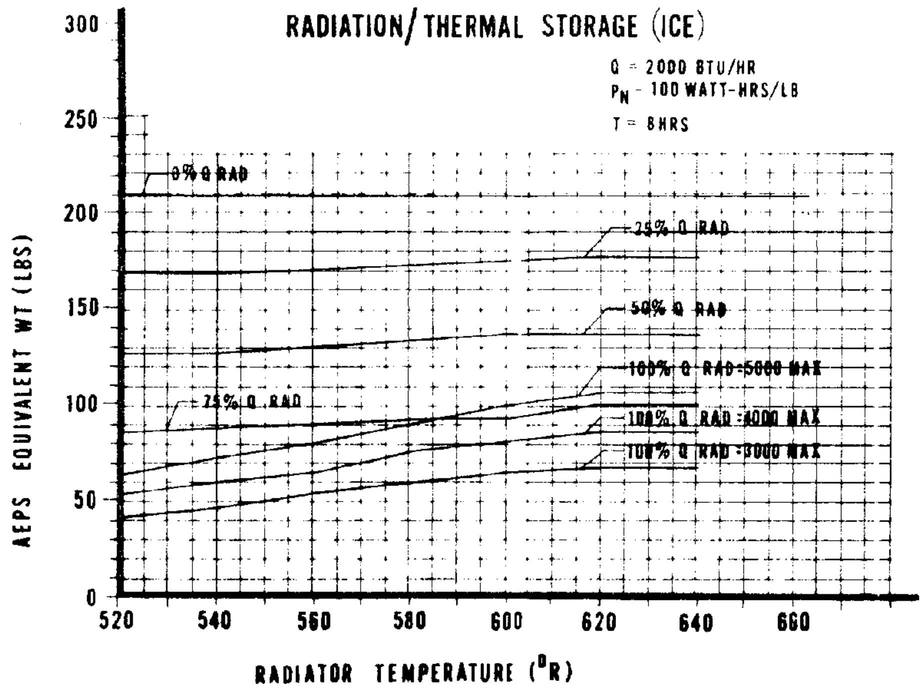

RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N = 200 WATT-HRS/LB
T = 8 HRS
100% Q RAD = 5000 MAX
100% Q RAD = 4000 MAX
Q RAD = 0
25% Q RAD
50% Q RAD
75% Q RAD
100% Q RAD = 3000 MAX
AEPS EQUIVALENT VOLUME (IN³)
RADIATOR TEMPERATUR (°R)
9000
8000
7000
6000
5000
4000
3000
520
540
560
580
600
620
640

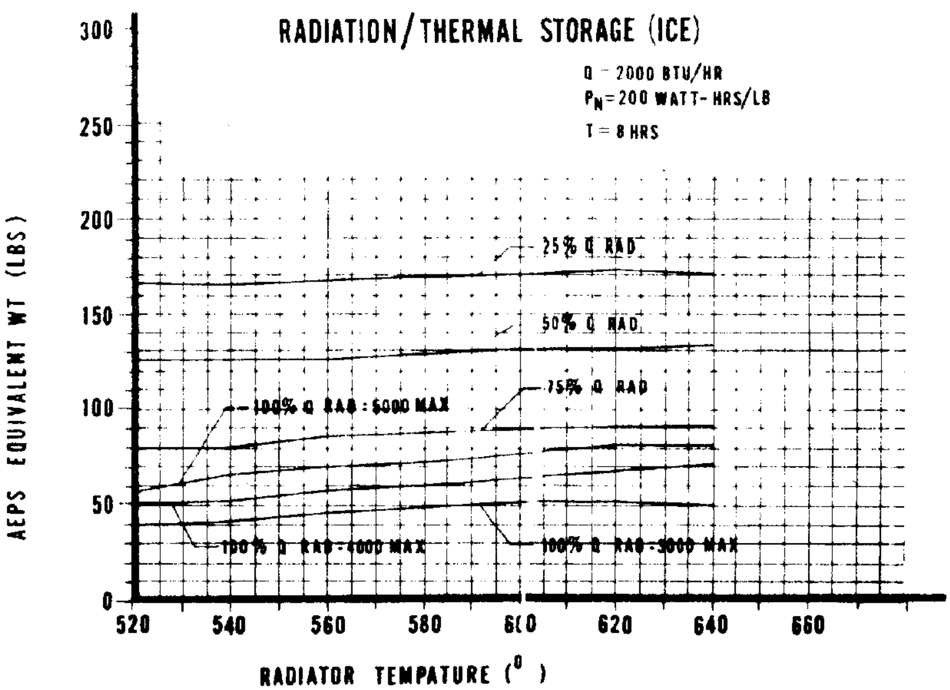


RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N = 100 WATT-HRS/LB
T = 4 HRS
Q RAD=0
25% Q RAD
100% Q RAD=5000 MAX
50% Q RAD
75% Q RAD
100% Q RAD=4000 MAX
100% Q RAD=3000 MAX
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)



RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N = 200 WATT-HRS/LB
T = 4 HRS
25% Q RAD
50% Q RAD
100% Q RAD = 5000 MAX
75% Q RAD
100% Q RAD = 4000 MAX
100% Q RAD = 3000 MAX
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)


RADIATION/THERMAL STORAGE (ICE)
Q = 2000 BTU/HR
P_N - 100 WATT-HRS/LB
T = 8 HRS
0% Q RAD
25% Q RAD
50% Q RAD
75% Q RAD
100% Q RAD-5000 MAX
100% Q RAD-4000 MAX
100% Q RAD-3000 MAX
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)
0
50
100
150
200
250
300
520
540
560
580
600
620
640
660


RADIATION/THERMAL STORAGE (ICE)
Q - 2000 BTU/HR
P_N = 200 WATT-HRS/LB
T = 8 HRS
25% Q RAD
50% Q RAD
75% Q RAD
100% Q RAD-5000 MAX
100% Q RAD-4000 MAX
100% Q RAD-3000 MAX
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPATURE (°)
0
50
100
150
200
250
300
520
540
560
580
600
620
640
660

CONCEPT 17 - RADIATION/THERMAL STORAGE (PH_4Cl)

This hybrid concept consists of two vapor compression cycles thermally interconnected in series by a thermal storage unit. The first vapor compression cycle transfers the total AEPS heat load from the evaporator to the PH_4Cl thermal storage unit. It is, therefore, sized on maximum thermal load and requires a thermal storage unit variable speed compressor and variable expansion valve to prevent over-cooling. The second vapor compression cycle transfers a portion of the thermal load transferred to the thermal storage unit to the radiator. Thus, a trade-off can be made between radiator size and thermal storage unit weight. In this system, the radiator size is based on the percentage of the average heat load transferred by the second vapor compression cycle and is, therefore, insensitive to the AEPS maximum heat load. Inherently flexible, this concept may be used or sized for a variety of operational modes. Humidity control is attained by a water separator and holding tank which removes and stores vent loop condensed moisture downstream of the first vapor compression cycle evaporator. The automatic TCV provides LCG temperature control. Because of its size, this system is only applicable to "cart" mounting and is, therefore, eliminated from consideration for the Space Station application.

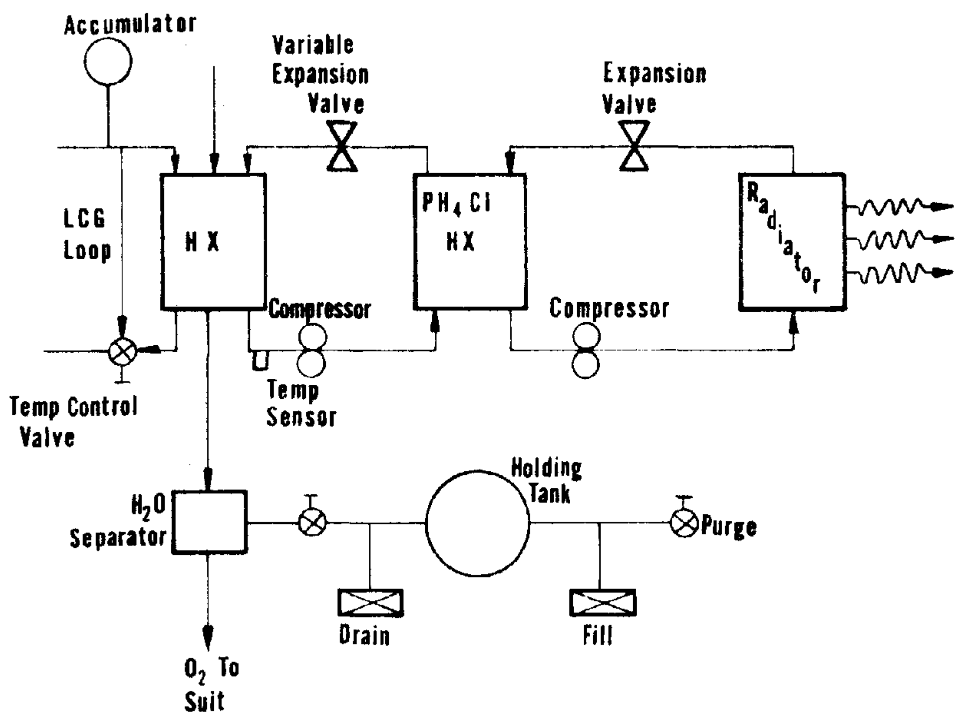
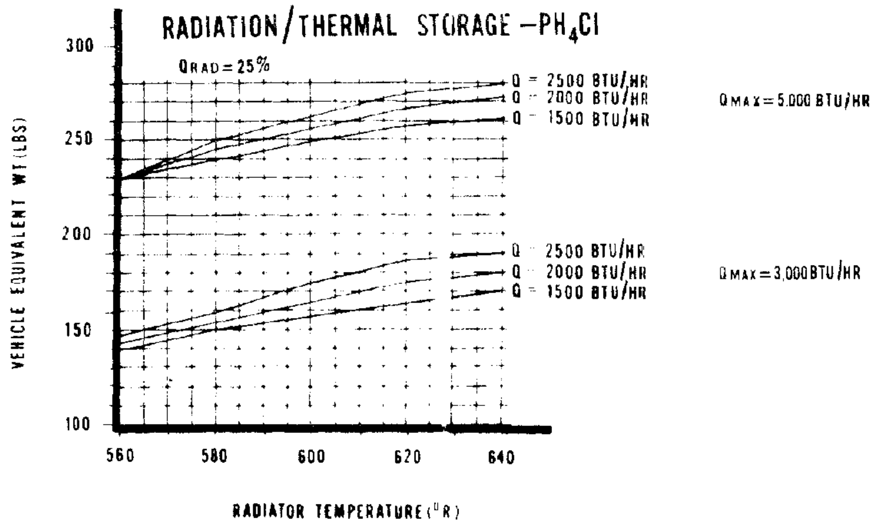
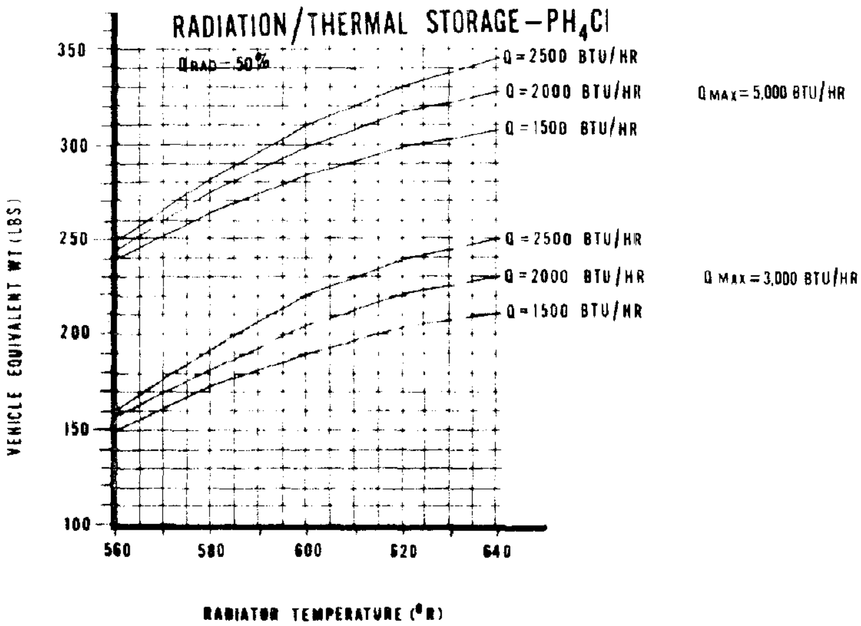


FIGURE 4–17. RADIATION/THERMAL STORAGE – PH_4Cl

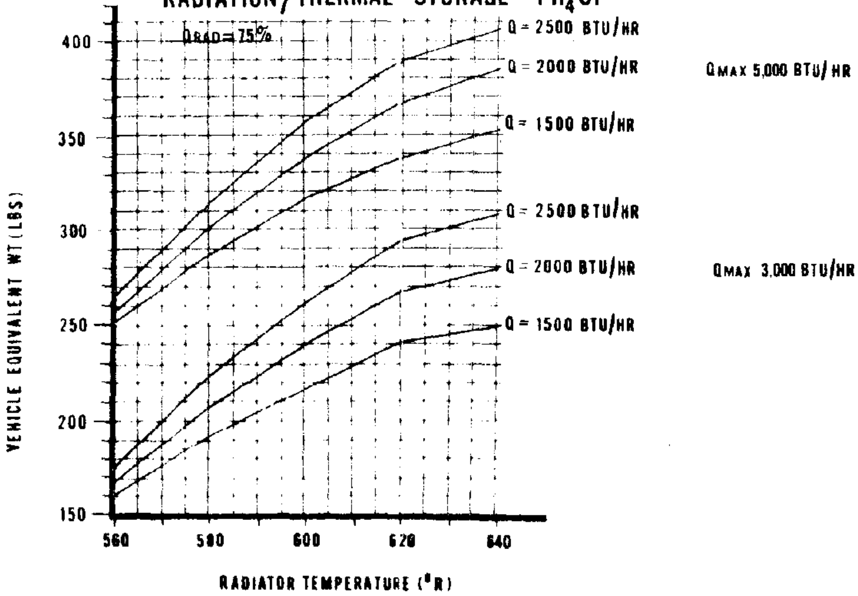


RADIATION/THERMAL STORAGE – PH_4Cl
Q_{RAD} = 25%
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
Q_{MAX} = 5,000 BTU/HR
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
Q_{MAX} = 3,000 BTU/HR
VEHICLE EQUIVALENT WT (LBS)
100
150
200
250
300
560
580
600
620
640
RADIATOR TEMPERATURE (°R)

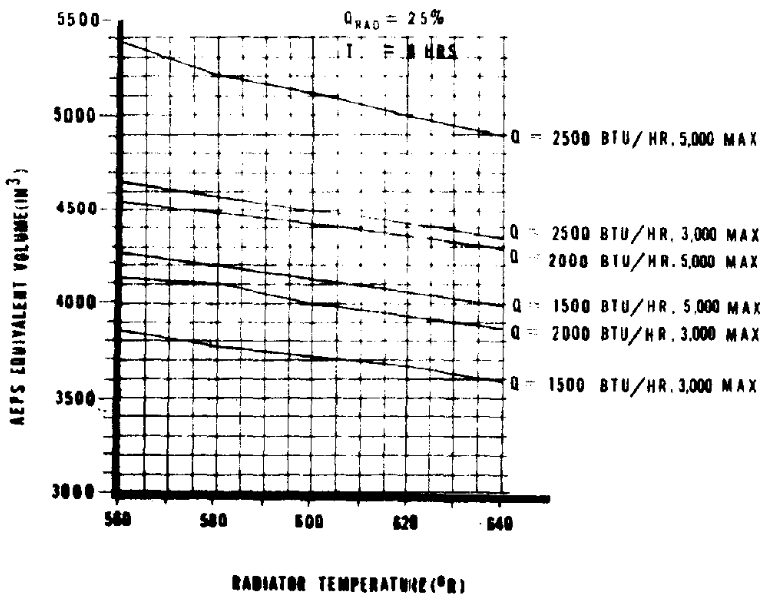


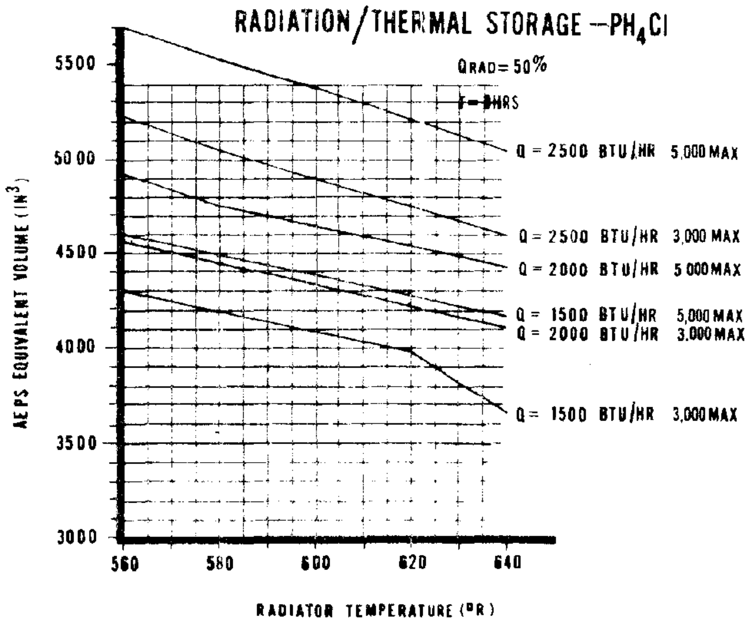
RADIATION/THERMAL STORAGE – PH_4Cl
Q_{RAD} = 50%
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
Q_{MAX} = 5,000 BTU/HR
Q = 2500 BTU/HR
Q = 2000 BTU/HR
Q = 1500 BTU/HR
Q_{MAX} = 3,000 BTU/HR
VEHICLE EQUIVALENT WT (LBS)
100
150
200
250
300
350
560
580
600
620
640
RADIATOR TEMPERATURE (°R)

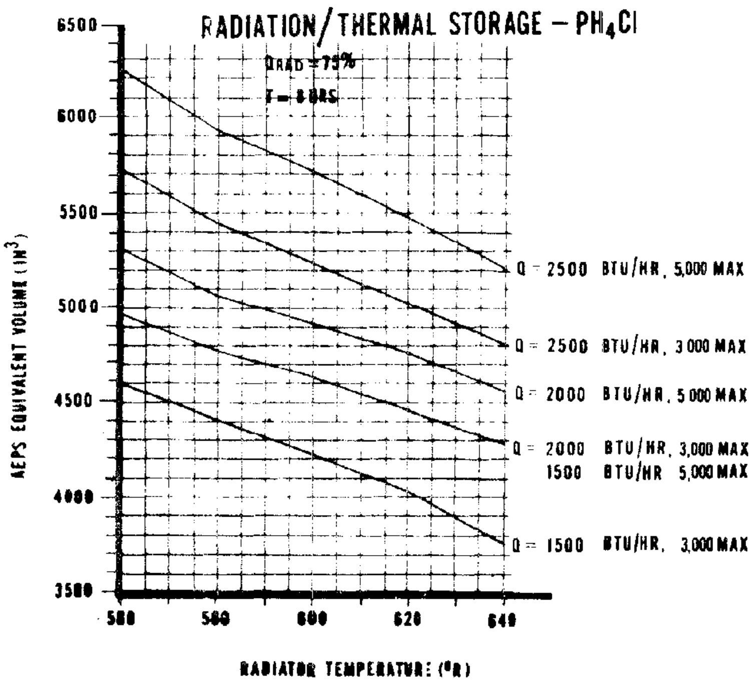
RADIATION/THERMAL STORAGE – PH_4Cl

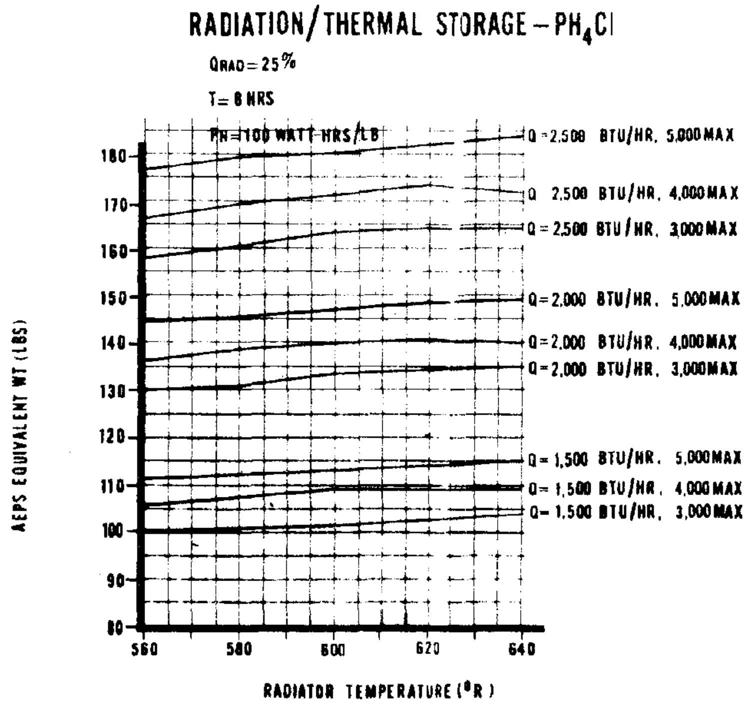


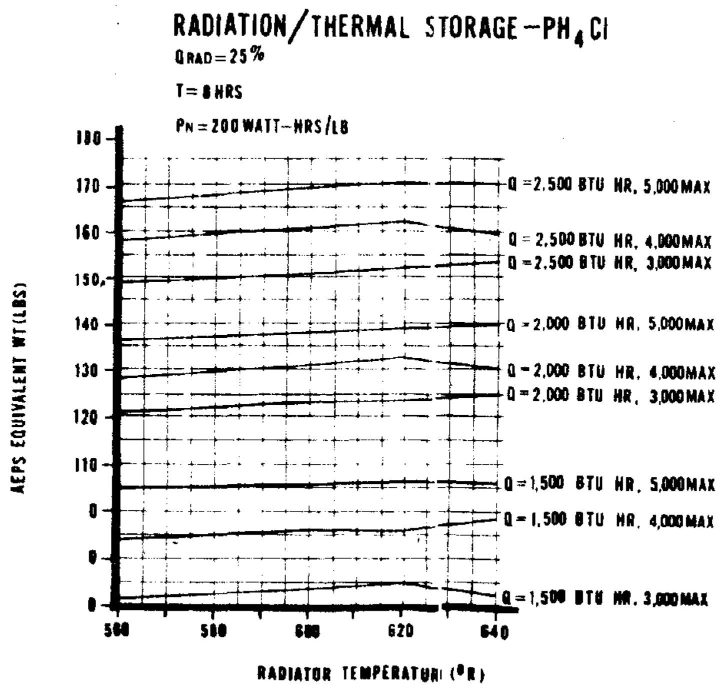
RADIATION/THERMAL STORAGE – PH_4Cl

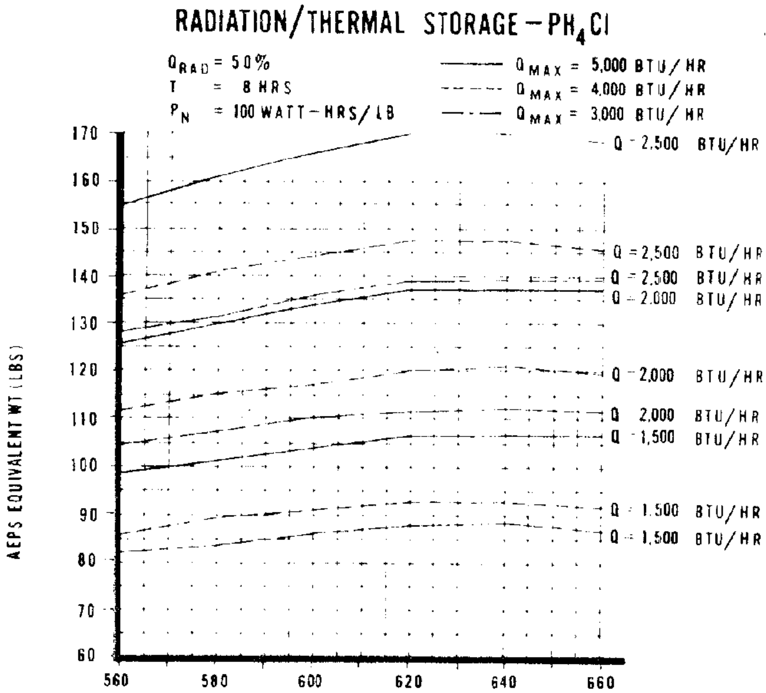


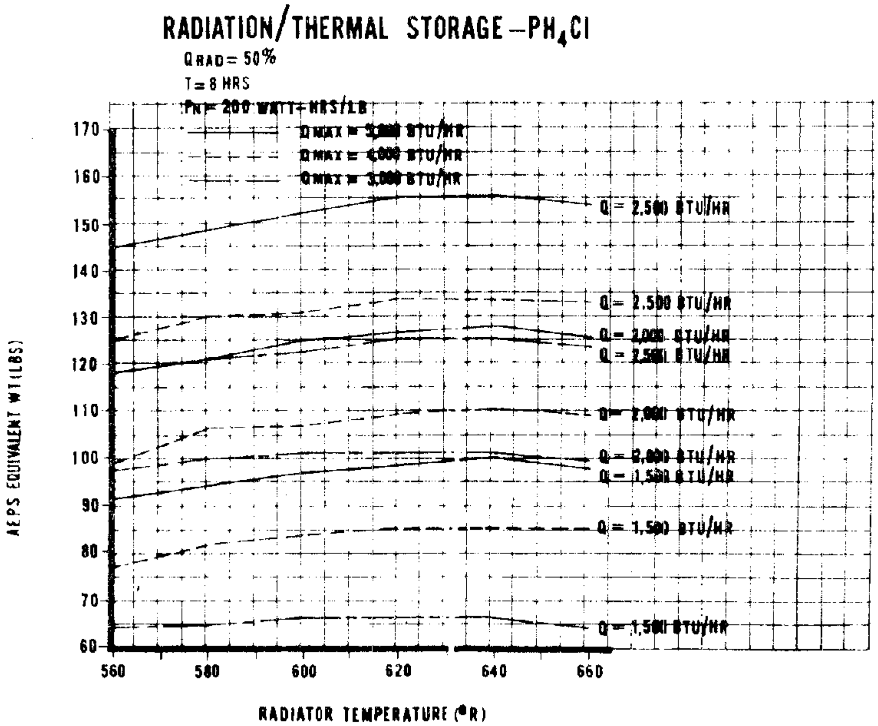

RADIATION/THERMAL STORAGE —PH_4Cl
QRAD= 50%
Q = 2500 BTU/HR 5,000 MAX
Q = 2500 BTU/HR 3,000 MAX
Q = 2000 BTU/HR 5 000 MAX
Q = 1500 BTU/HR 5,000 MAX
Q = 2000 BTU/HR 3,000 MAX
Q = 1500 BTU/HR 3,000 MAX
5500
5000
4500
4000
3500
3000
560
580
600
620
640
AEPS EQUIVALENT VOLUME (IN^3)
RADIATOR TEMPERATURE (°R)

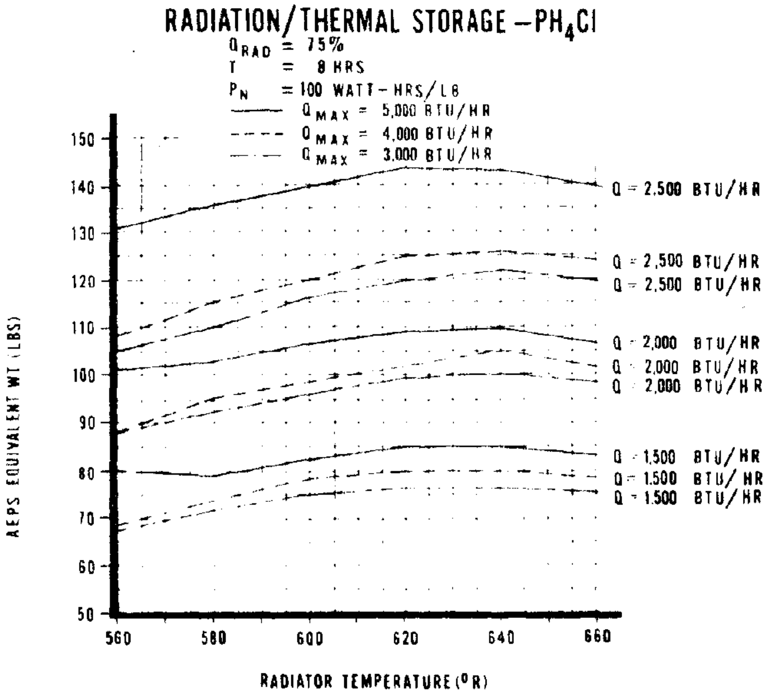

RADIATION/THERMAL STORAGE – PH_4Cl
Q = 2500 BTU/HR, 5,000 MAX
Q = 2500 BTU/HR, 3 000 MAX
Q = 2000 BTU/HR, 5 000 MAX
Q = 2000 BTU/HR, 3,000 MAX
1500 BTU/HR 5,000 MAX
Q = 1500 BTU/HR, 3,000 MAX
6500
6000
5500
5000
4500
3500
620
AEPS EQUIVALENT VOLUME (IN^3)

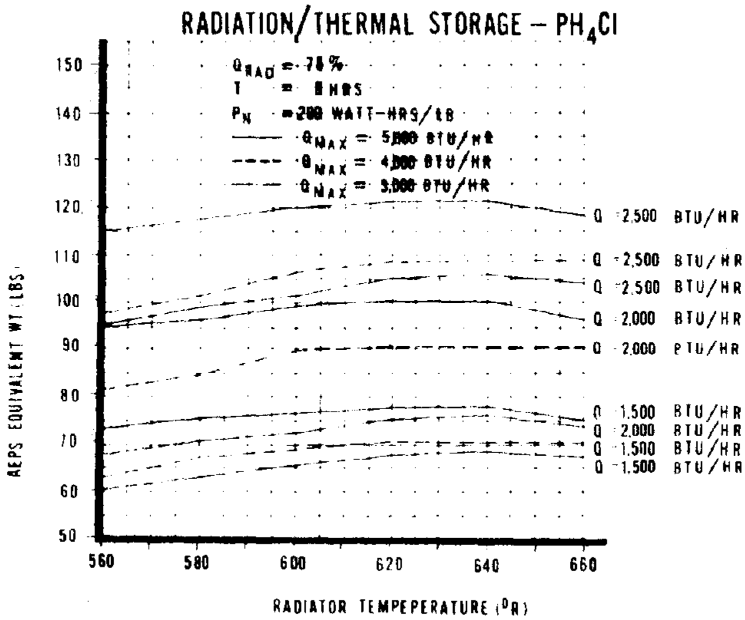

RADIATION/THERMAL STORAGE – PH_4Cl
QRAD = 25%
T = 8 HRS
PN = 100 WATT-HRS/LB
Q = 2,500 BTU/HR, 5,000 MAX
Q 2,500 BTU/HR, 4,000 MAX
Q = 2,500 BTU/HR, 3,000 MAX
Q = 2,000 BTU/HR, 5,000 MAX
Q = 2,000 BTU/HR, 4,000 MAX
Q = 2,000 BTU/HR, 3,000 MAX
Q = 1,500 BTU/HR, 5,000 MAX
Q = 1,500 BTU/HR, 4,000 MAX
Q = 1,500 BTU/HR, 3,000 MAX
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)


RADIATION/THERMAL STORAGE – PH_4Cl
QRAD = 25%
T = 8 HRS
PN = 200 WATT-HRS/LB
Q = 2,500 BTU HR, 5,000 MAX
Q = 2,500 BTU HR, 4,000 MAX
Q = 2,500 BTU HR, 3,000 MAX
Q = 2,000 BTU HR, 5,000 MAX
Q = 2,000 BTU HR, 4,000 MAX
Q = 2,000 BTU HR, 3,000 MAX
Q = 1,500 BTU HR, 5,000 MAX
Q = 1,500 BTU HR, 4,000 MAX
Q = 1,500 BTU HR, 3,000 MAX
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)


RADIATION/THERMAL STORAGE – PH4Cl
QRAD = 50%
T = 8 HRS
PN = 100 WATT-HRS/LB
QMAX = 5,000 BTU/HR
QMAX = 4,000 BTU/HR
QMAX = 3,000 BTU/HR
Q = 2,500 BTU/HR
Q = 2,000 BTU/HR
Q = 1,500 BTU/HR
AEPS EQUIVALENT WT (LBS)


RADIATION/THERMAL STORAGE – PH4Cl
QRAD = 50%
T = 8 HRS
PN = 200 WATT-HRS/LB
Q = 2,500 BTU/HR
Q = 2,000 BTU/HR
Q = 1,500 BTU/HR
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)


RADIATION/THERMAL STORAGE – PH_4Cl
Q_{RAD} = 75%
T = 8 HRS
P_N = 100 WATT-HRS/LB
Q_{MAX} = 5,000 BTU/HR
Q_{MAX} = 4,000 BTU/HR
Q_{MAX} = 3,000 BTU/HR
Q = 2,500 BTU/HR
Q = 2,500 BTU/HR
Q = 2,500 BTU/HR
Q = 2,000 BTU/HR
Q = 2,000 BTU/HR
Q = 2,000 BTU/HR
Q = 1,500 BTU/HR
Q = 1,500 BTU/HR
Q = 1,500 BTU/HR
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPERATURE (°R)


RADIATION/THERMAL STORAGE – PH_4Cl
Q_{RAD} = 75%
T = 8 HRS
P_N = 200 WATT-HRS/LB
Q_{MAX} = 5,000 BTU/HR
Q_{MAX} = 4,000 BTU/HR
Q_{MAX} = 3,000 BTU/HR
Q = 2,500 BTU/HR
Q = 2,500 BTU/HR
Q = 2,500 BTU/HR
Q = 2,000 BTU/HR
Q = 2,000 BTU/HR
Q = 1,500 BTU/HR
Q = 2,000 BTU/HR
Q = 1,500 BTU/HR
Q = 1,500 BTU/HR
AEPS EQUIVALENT WT (LBS)
RADIATOR TEMPEPERATURE (°R)

CONCEPT 18 - THERMAL STORAGE/H_2O ADSORPTION

This concept is similar to Concept 8 - Direct Cooling via H_2O Adsorption/Radiation, except the radiator has been replaced by a thermal storage unit. The heat of vaporization of water in the evaporator provides direct cooling of the LCG and vent loops. LCG temperature control is achieved by the automatic TCV. The evaporator is fed water by a pressurized bladder tank. Water flow rate is controlled by a solenoid valve and controller as a function of LCG evaporator outlet temperature. The evaporator effluent water vapor is adsorbed by sodium selenide in the adsorber, the heat of adsorption being stored by the heat of condensation of PH_4Cl in the thermal storage unit. PH_4Cl sizing is based on total integrated heat of adsorption. Sodium selenide was chosen as the adsorbent over LiBr, LiCl and $CaCl_2$ because it has the lowest total integrated heat of adsorption. Adequate design margin on chemical sizing and insuring good water vapor flow distribution by the proper adsorber configuration insures that the hydrated sodium selenide crystal does not go into solution with the water. The feedwater is reclaimed in the vehicle by desorbing the chemical by an electrical heater and recondensing the effluent water vapor.

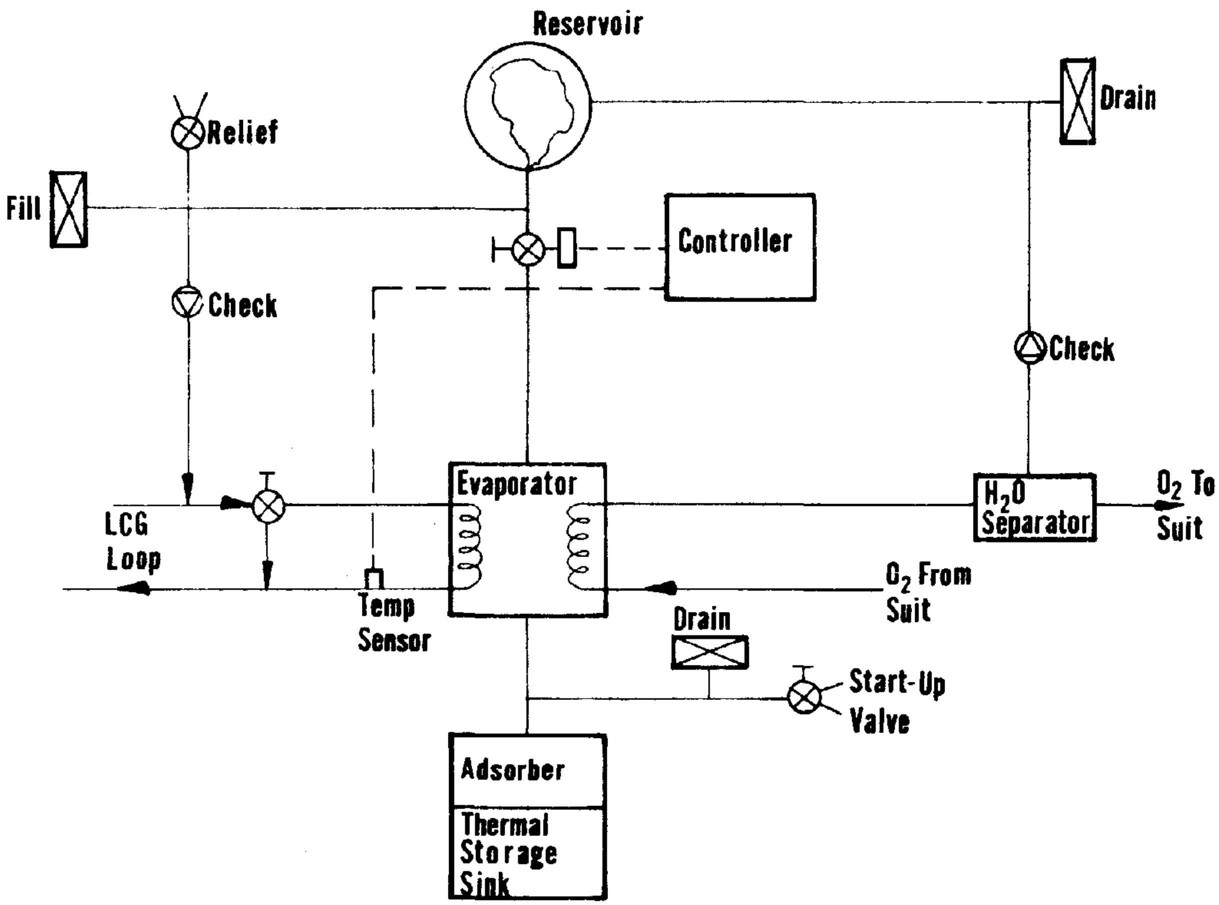
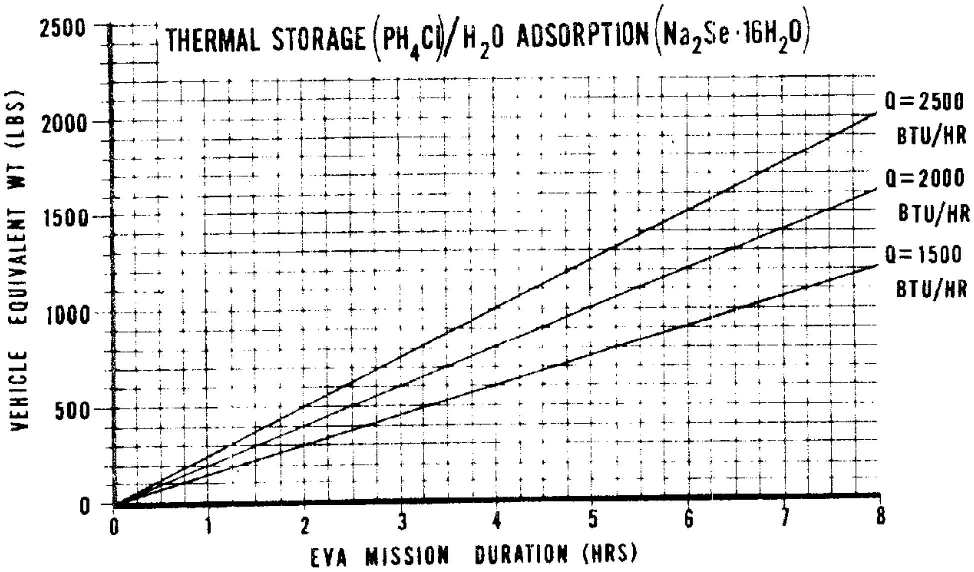
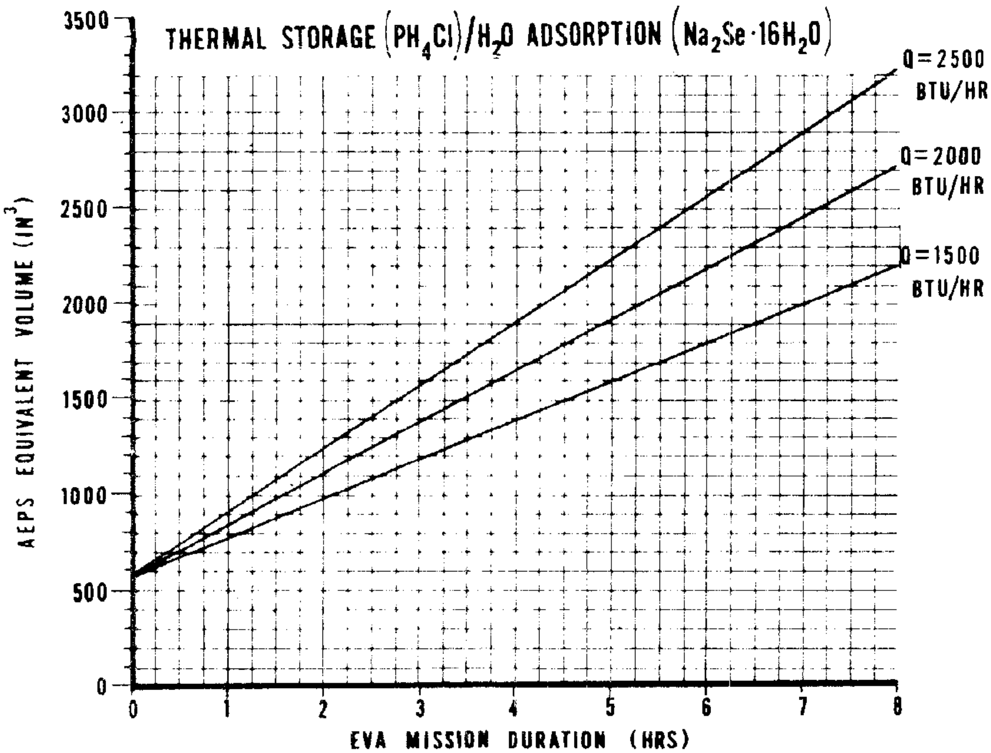
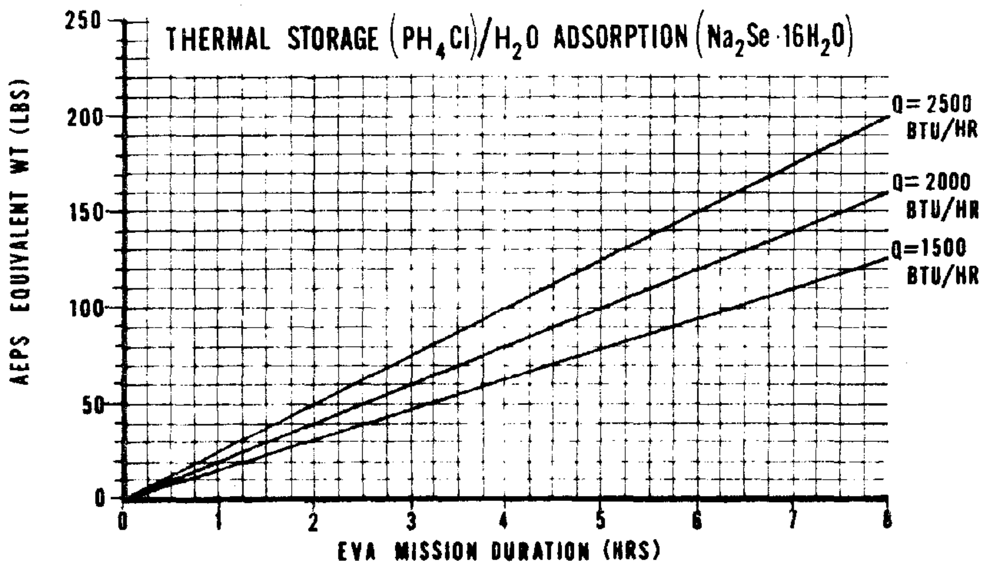
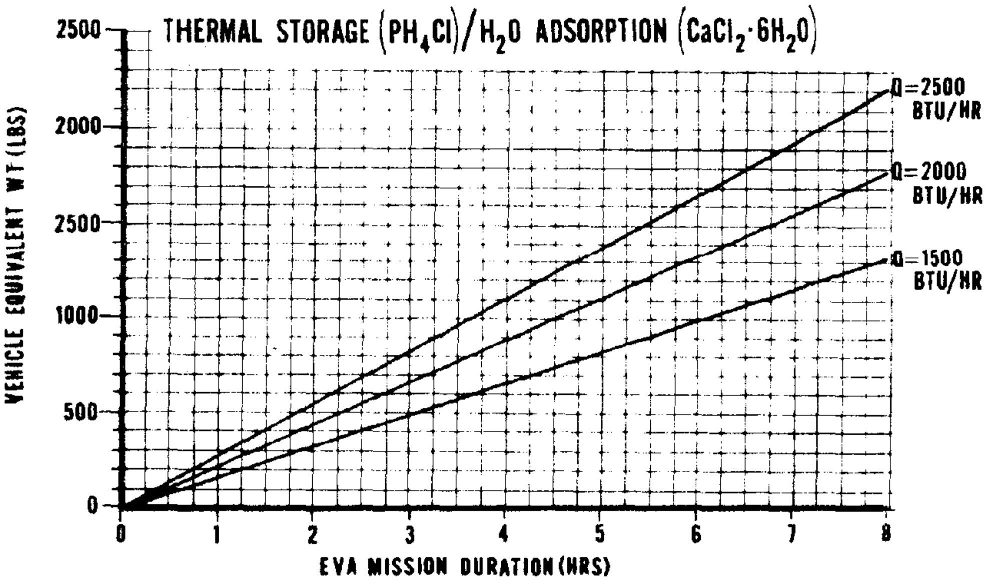


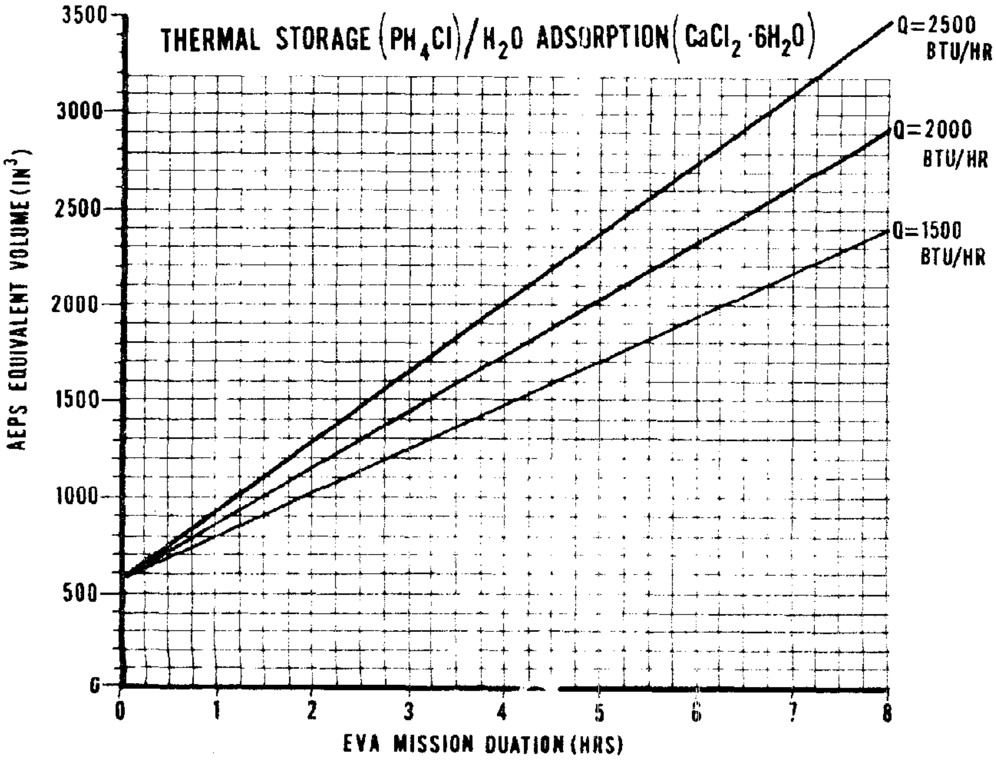
FIGURE 4—18. THERMAL STORAGE/H_2O ADSORPTION


THERMAL STORAGE (PH4Cl)/H2O ADSORPTION (Na2Se·16H2O)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
VEHICLE EQUIVALENT WT (LBS)
EVA MISSION DURATION (HRS)
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8

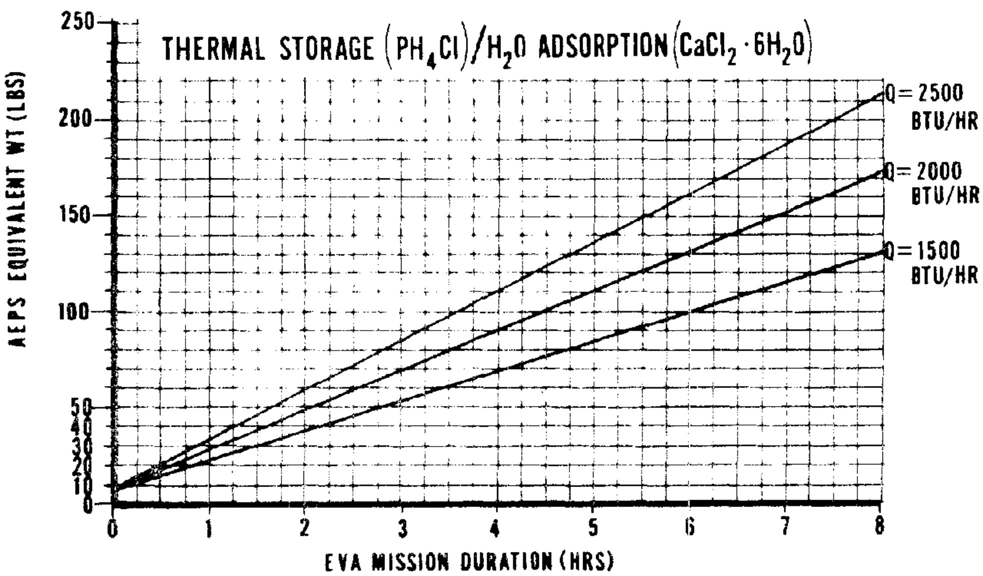

THERMAL STORAGE (PH4Cl)/H2O ADSORPTION (Na2Se·16H2O)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
AEPS EQUIVALENT VOLUME (IN3)
EVA MISSION DURATION (HRS)
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8


THERMAL STORAGE (PH4Cl)/H2O ADSORPTION (Na2Se·16H2O)
AEPS EQUIVALENT WT (LBS)
250
200
150
100
50
0
Q= 2500 BTU/HR
Q= 2000 BTU/HR
Q=1500 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


THERMAL STORAGE (PH4Cl)/H2O ADSORPTION (CaCl2·6H2O)
VEHICLE EQUIVALENT WT (LBS)
2500
2000
2500
1000
500
0
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)



THERMAL STORAGE $(PH_4Cl)/H_2O$ ADSORPTION $(CaCl_2 \cdot 6H_2O)$
AEPS EQUIVALENT VOLUME (IN^3)
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
EVA MISSION DUATION (HRS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR



THERMAL STORAGE $(PH_4Cl)/H_2O$ ADSORPTION $(CaCl_2 \cdot 6H_2O)$
AEPS EQUIVALENT WT (LBS)
250
200
150
100
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=2000 BTU/HR
Q=1500 BTU/HR

4.1.2 CO_2 CONTROL/O_2 SUPPLY

CONCEPT 1 - LITHIUM HYDROXIDE (LiOH)

Lithium hydroxide, a non-regenerable solid absorbent, is packaged in replaceable cartridges which also may contain a particulate filter and activated charcoal for trace contaminant control. The LiOH contains 4 to 8% water and must be stored in protective containers in a temperature controlled environment to ensure maximum performance.

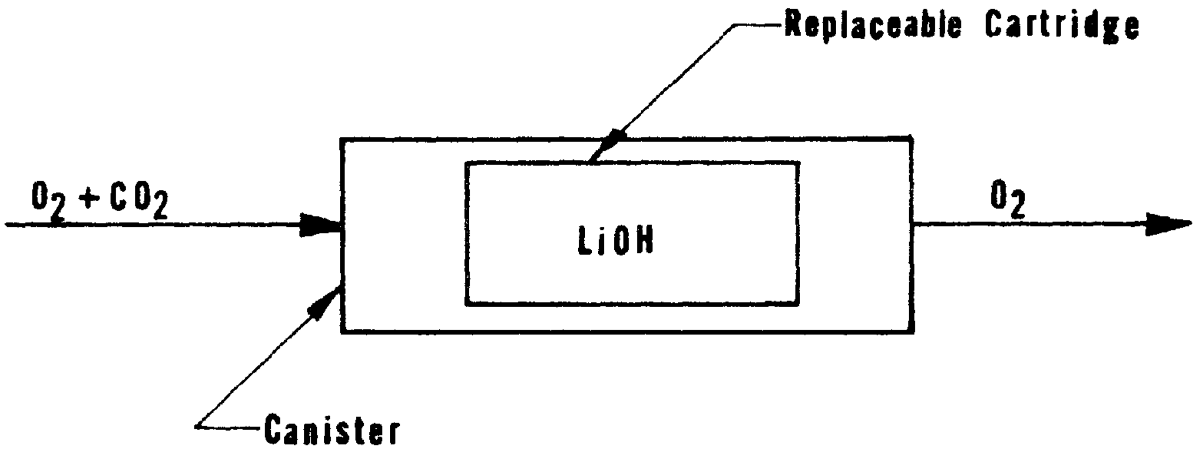
After each use, the cartridge is replaced in the canister regardless of the total time or use rate accumulated on the unit. This procedure ensures a fully operational charge for each mission but has a built-in unrecoverable waste which is the unused portion of the adsorbent plus the cartridge (unless the used cartridge is then utilized in the vehicle ECS). In use, the vent loop returning from the astronaut is directed to the LiOH where the following reactions occur:

$$LiOH + H_2O(g) \longrightarrow LiOH \cdot H_2O$$

$$2\ LiOH \cdot H_2O + CO_2 \longrightarrow Li_2CO_3 + 3H_2O(g)$$

$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O(g)$$

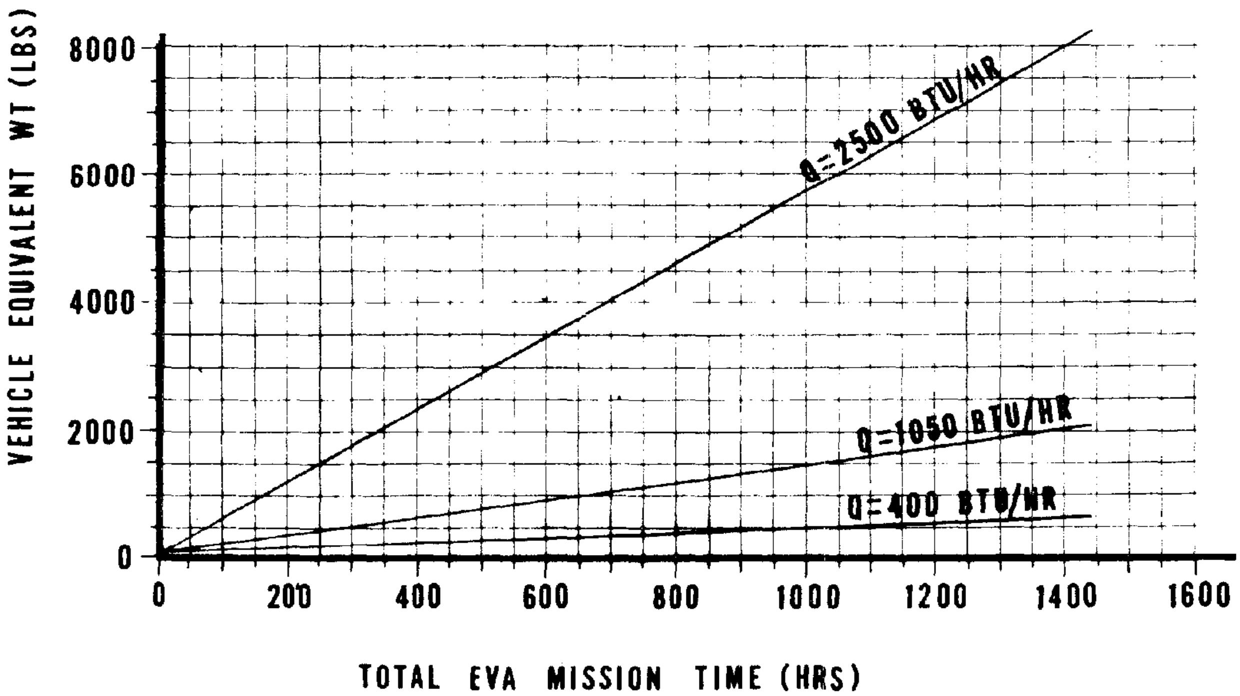
There is a net energy and water vapor production in the process which is removed in the thermal/humidity control subsystem. Outlet CO_2 concentration remains near zero for almost 80% of the useful life, thus providing the astronaut an extremely low time-averaged CO_2 atmosphere. The following curves are based on a LiOH utilization efficiency of 53% at an average metabolic load of 1050 BTU/hr.

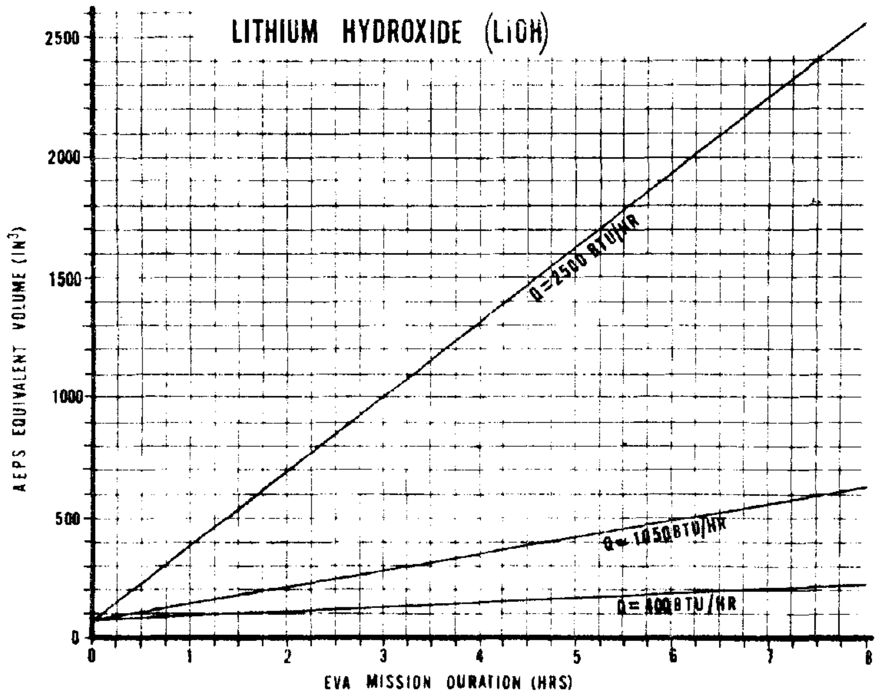


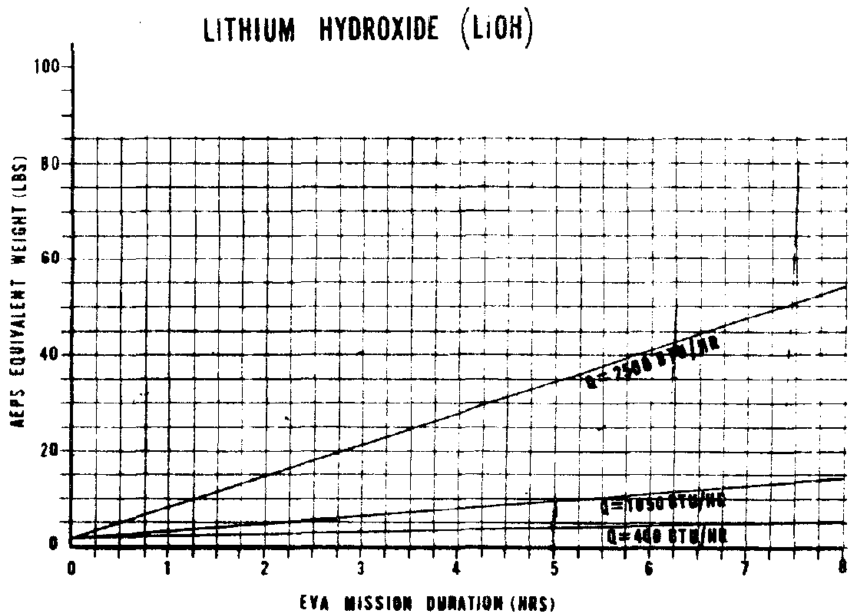
$$2\,LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

FIGURE 4–19. LITHIUM HYDROXIDE (LiOH)

LITHIUM HYDROXIDE (LiOH)




LITHIUM HYDROXIDE (LiOH)
2500
2000
1500
1000
500
0
AEPS EQUIVALENT VOLUME (IN³)
Q=2500 BTU/HR
Q=1050 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


LITHIUM HYDROXIDE (LiOH)
100
80
60
40
20
0
AEPS EQUIVALENT WEIGHT (LBS)
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)

Cooled lithium hydroxide, a concept similar to the previously described concept, takes advantage of the liquid cooling loop to remove the heat of reaction from the absorbing bed. Cooler operation stimulates the formation of $LiOH \cdot H_2O$ which, in turn, increases bed reactivity toward CO_2 absorption.

In comparison to uncooled LiOH, this concept offers the advantage of reduced volume plus minimum storage environment constraint as pure LiOH is the raw material and stringent temperature control is not required. However, cooling coils and quick disconnects do add to subsystem volume and weight.

As shown in the nonregenerable CO_2 sorbents comparison curves (Figure 4-20), cooling the LiOH bed provides the greatest advantage at high metabolic rates ($>$ 1200 BTU/hr) and at high allowable outlet CO_2 concentrations ($ppCO_2 >$ 7 mm Hg). The following parametric curves are based on a cooled LiOH utilization efficiency of 60% at an average metabolic load of 1050 BTU/hr.

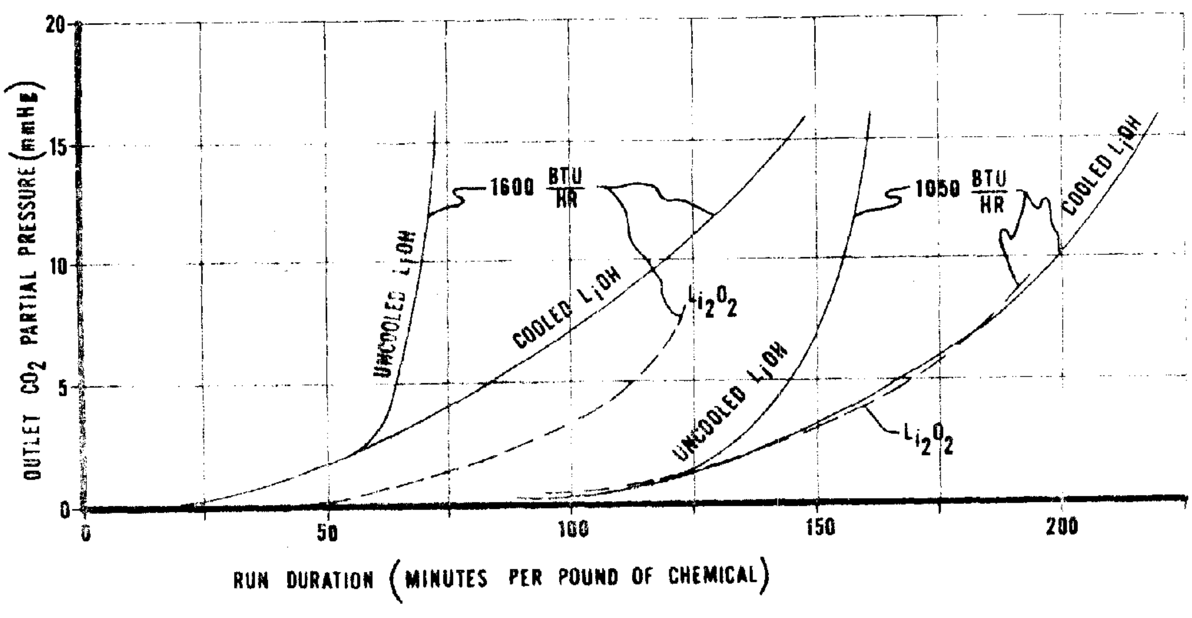
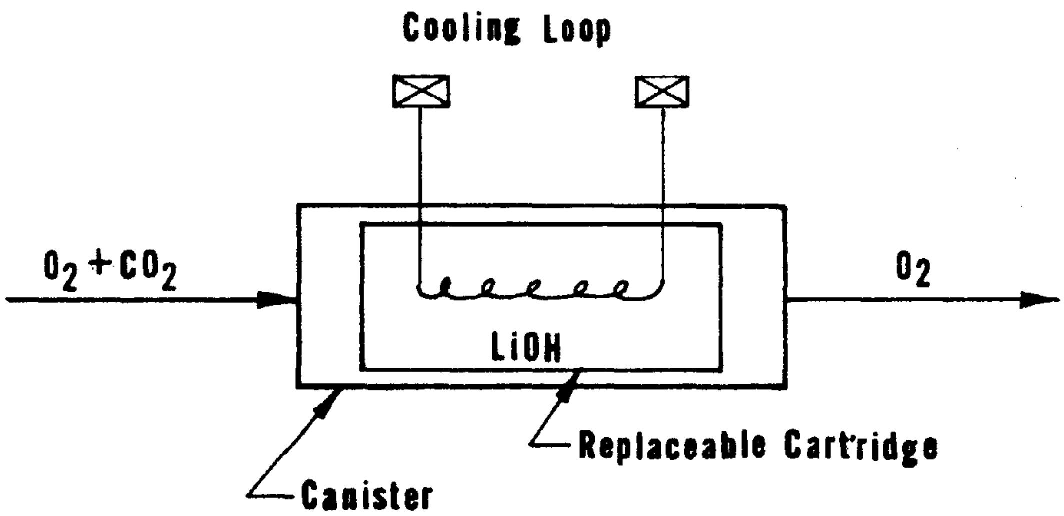
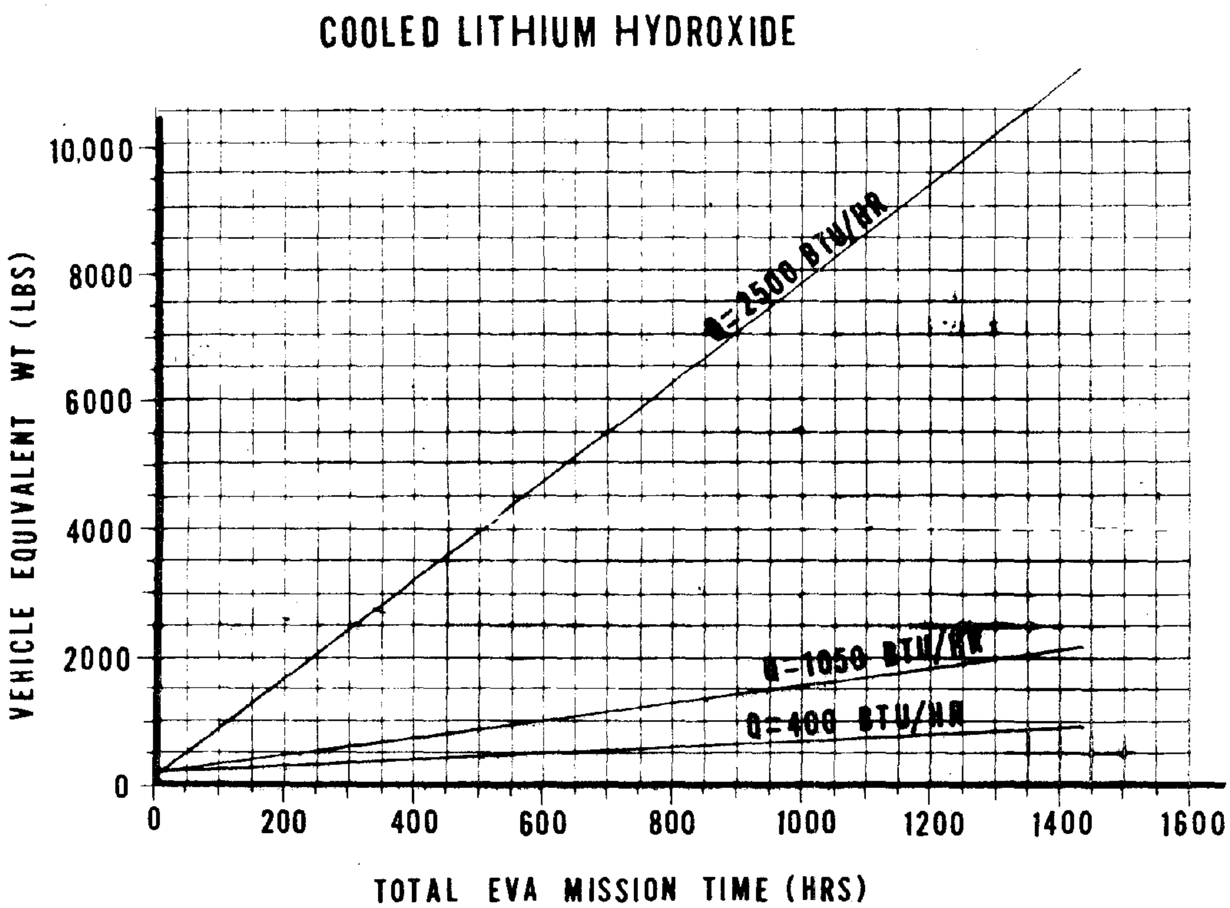


FIGURE 4-20. NONREGENERABLE SOLID CO_2 SORBENTS COMPARISON

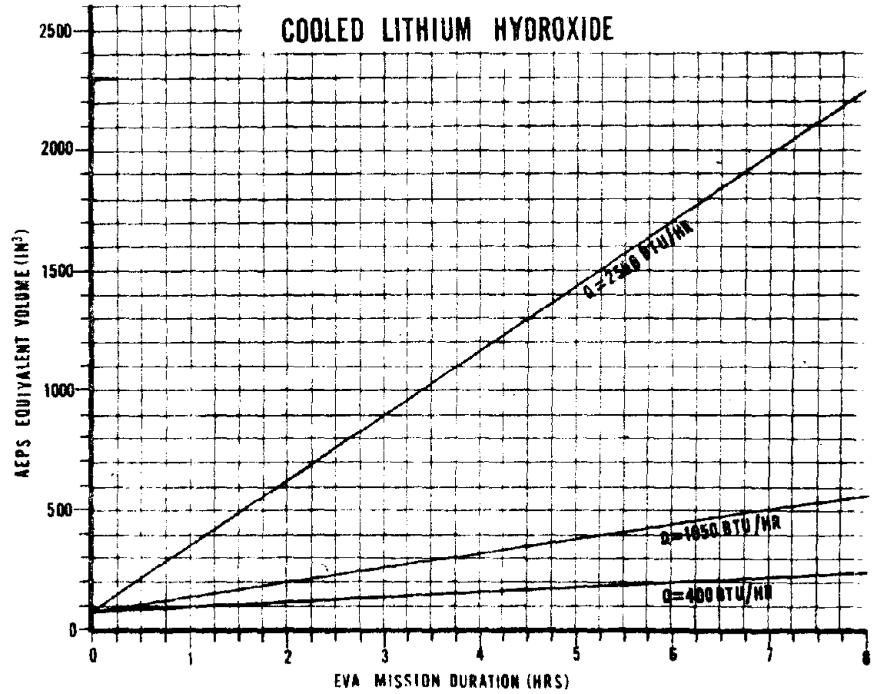


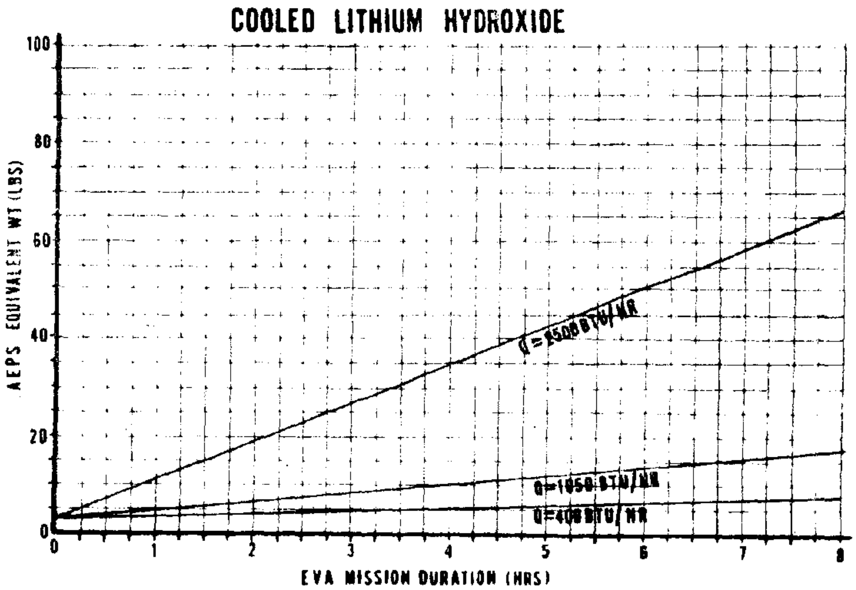
$$2\,LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

FIGURE 4–21. COOLED LITHIUM HYDROXIDE



COOLED LITHIUM HYDROXIDE
10,000
8000
6000
4000
2000
0
VEHICLE EQUIVALENT WT (LBS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)


COOLED LITHIUM HYDROXIDE
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
500
1000
1500
2000
2500
0
1
2
3
4
5
6
7
8


COOLED LITHIUM HYDROXIDE
AEPS EQUIVALENT WT (LBS)
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
20
40
60
80
100
0
1
2
3
4
5
6
7
8

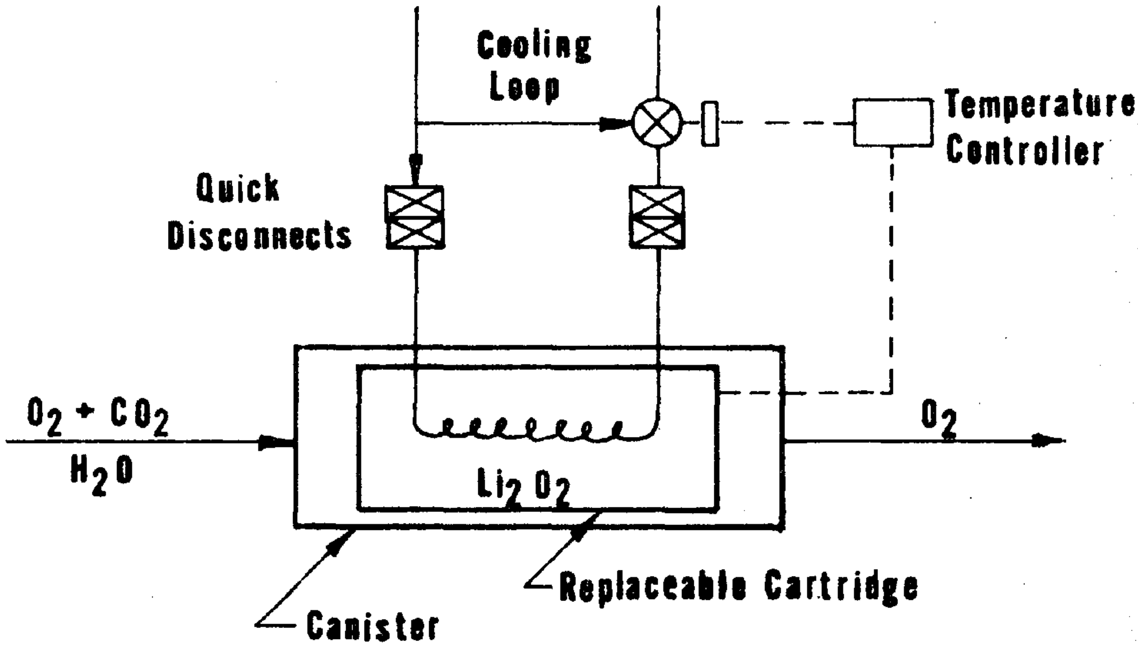
CONCEPT 3 - LITHIUM PEROXIDE (Li_2O_2)

Lithium peroxide, Li_2O_2, reacts with water vapor and CO_2 according to the following reactions:

$$Li_2O_2 + H_2O \longrightarrow 2LiOH + 1/2\ O_2$$
$$LiOH + H_2O \longrightarrow LiOH \cdot H_2O$$
$$2LiOH \cdot H_2O + CO_2 \longrightarrow Li_2CO_3 + 3H_2O$$
$$Li_2O_2 + CO_2 \longrightarrow Li_2CO_3 + 1/2\ O_2$$

A non-regenerable solid absorbent, Li_2O_2 is supplied in cartridges which are replaced after each mission. In addition to CO_2 control, the chemical provides approximately one-half the metabolic oxygen requirement. Temperature control of the reacting bed is necessary to obtain acceptable performance over widely varying metabolic rates. Over-cooling minimizes oxygen production while under-cooling can result in excessive O_2 production and poor CO_2 control. The addition of catalysts has been shown to be effective in stimulating O_2 production at lower temperatures.

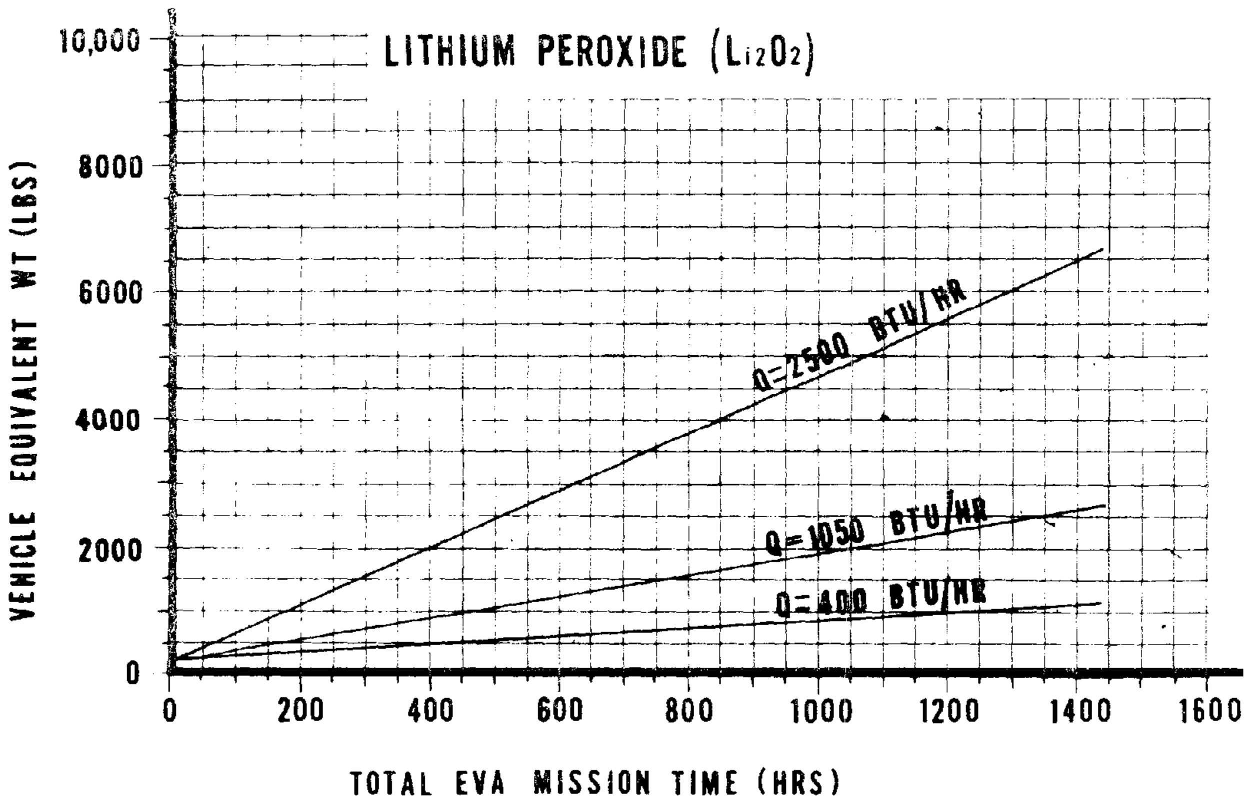
Usefulness of the concept is hindered by the low (relative to LiOH) chemical density and the requirement for cooling and subsequent temperature control. In a manner similar to cooled LiOH, Li_2O_2 is advantageous at high metabolic loads where performance degradation of uncooled LiOH is most rapid. The following curves are based on a Li_2O_2 utilization efficiency of 58% at an average metabolic load of 1050 BTU/hr.



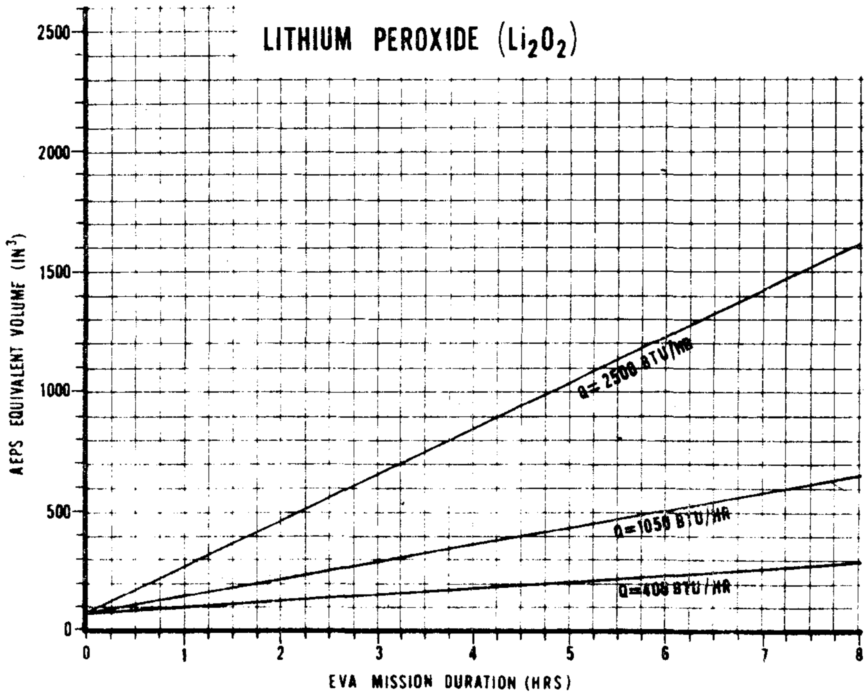
$$Li_2O_2 + H_2O \longrightarrow 2\,LiOH + O_2 + Q$$

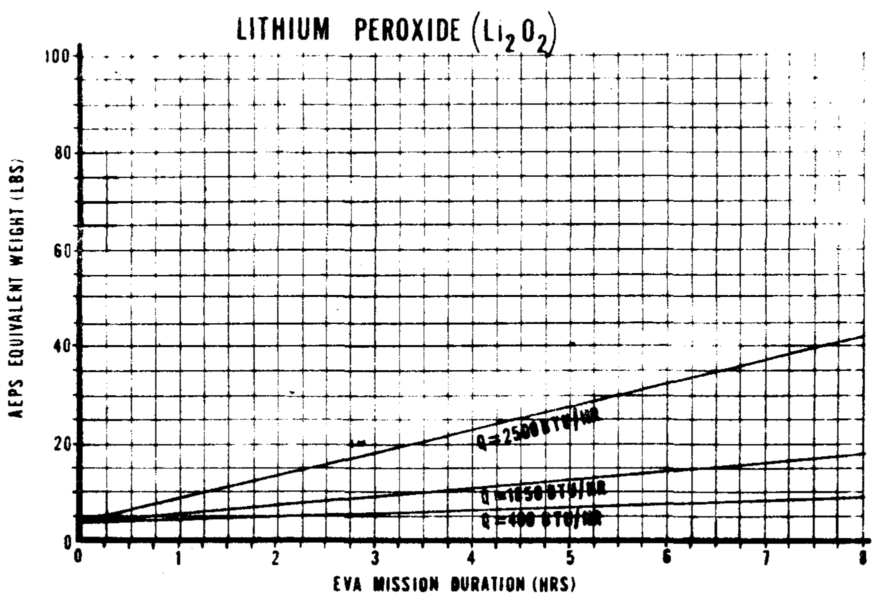
$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

FIGURE 4–22. LITHIUM PEROXIDE (Li_2O_2)



LITHIUM PEROXIDE (Li_2O_2)
VEHICLE EQUIVALENT WT (LBS)
10,000
8000
6000
4000
2000
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)


LITHIUM PEROXIDE (Li_2O_2)
AEPS EQUIVALENT VOLUME (IN^3)
EVA MISSION DURATION (HRS)
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR


LITHIUM PEROXIDE (Li_2O_2)
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR

CONCEPTS 4 & 5 - METALLIC OXIDE (VEHICLE REGENERABLE)

Metallic oxides (i.e. ZnO, MgO) react with CO_2 according to the following reversible reaction:

$$MO + CO_2 \rightleftharpoons MCO_3 + Q$$

As shown in Figure 4-23, the carbonate readily decomposes with increasing temperature and, in some cases, may be solely vacuum regenerable.

Excessive volume change during the adsorb/desorb cycle affects the chemical's physical stability and is a prime consideration in any future development effort. For this study, the adsorbent was contained between screens with gas flow over rather than through the packing. CO_2 diffusion into the thin oxide bed will be sufficient as long as the solid volume transition during adsorb/desorb does not result in an impregnable surface or if an extremely fine screen is not required. An alternate concept would consider a carrier to stabilize the solid adsorbent—possibly a thin layer of the oxide flame-sprayed on a screen matrix.

In the vehicle regenerable configuration, the adsorbent is packaged in a cartridge which is replaced after each mission. An oven/vacuum chamber will be provided within the vehicle for cartridge regeneration. Although not considered in the evaluation, reclamation of the oxygen is possible with this system by directing the desorbed gas to the vehicle CO_2 reduction system.

Other advantages of the concept include the visual inspection of the packed beds after each use and simple replacement, should it be required. Parametric data for CO_2 control/O_2 supply subsystems utilizing magnesium oxide (MgO) and zinc oxide (ZnO) to provide CO_2 control are presented on the following pages and are based on a utilization efficiency of 50% at an average metabolic load of 1050 BTU/hr.

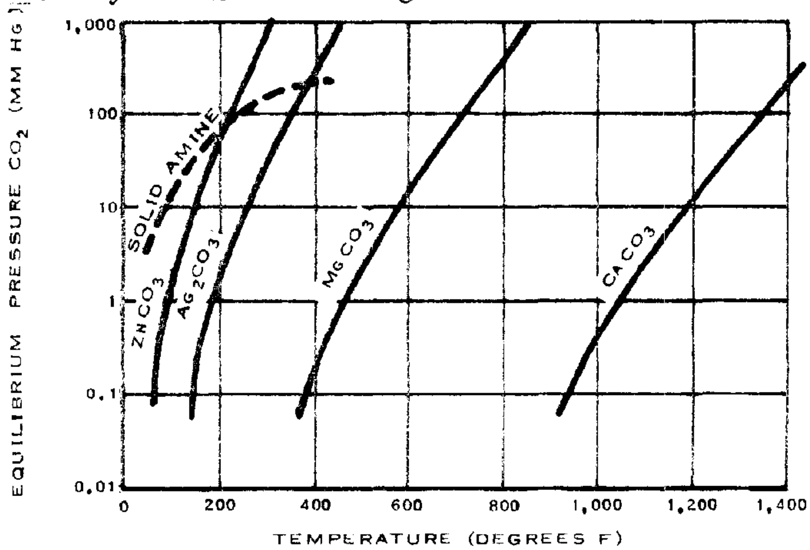


FIGURE 4-23. EQUILIBRIUM PRESSURES — REGENERABLE CO_2 SORBENTS

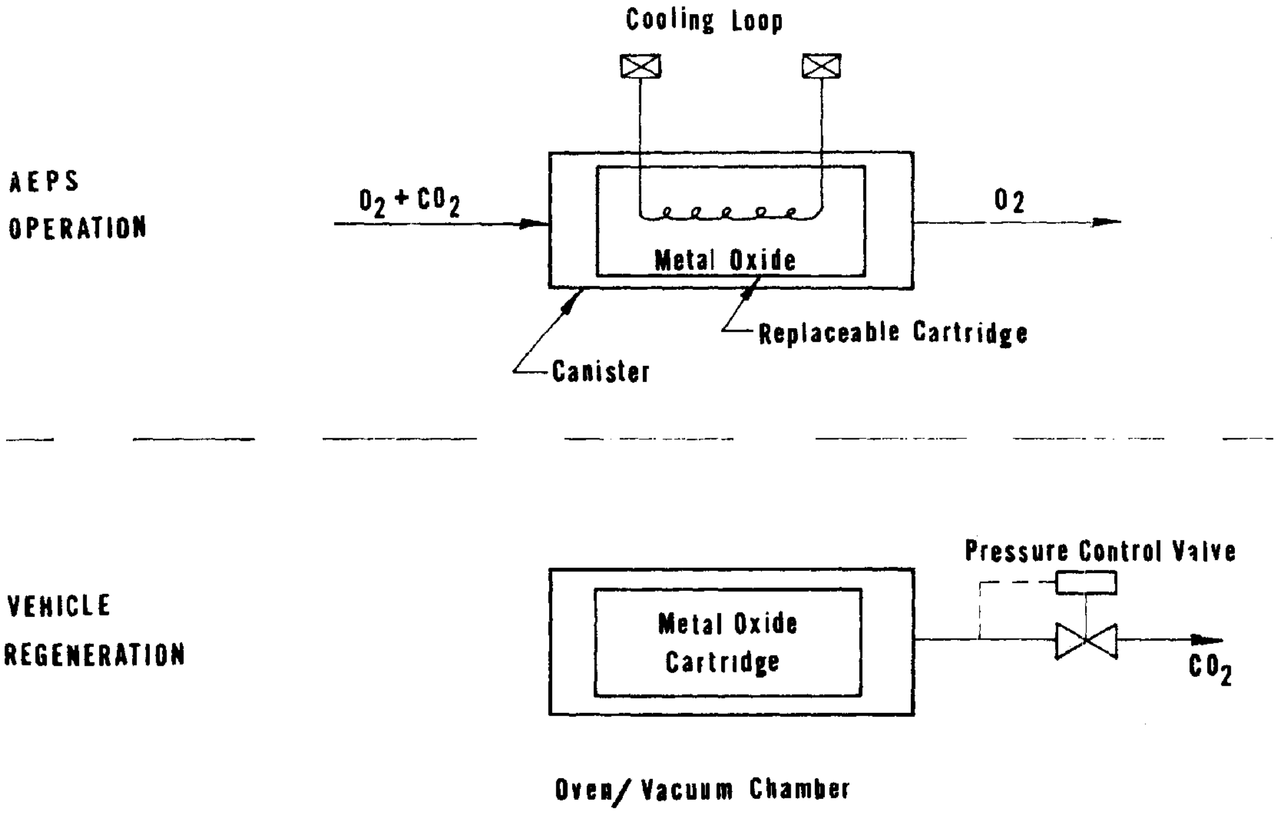
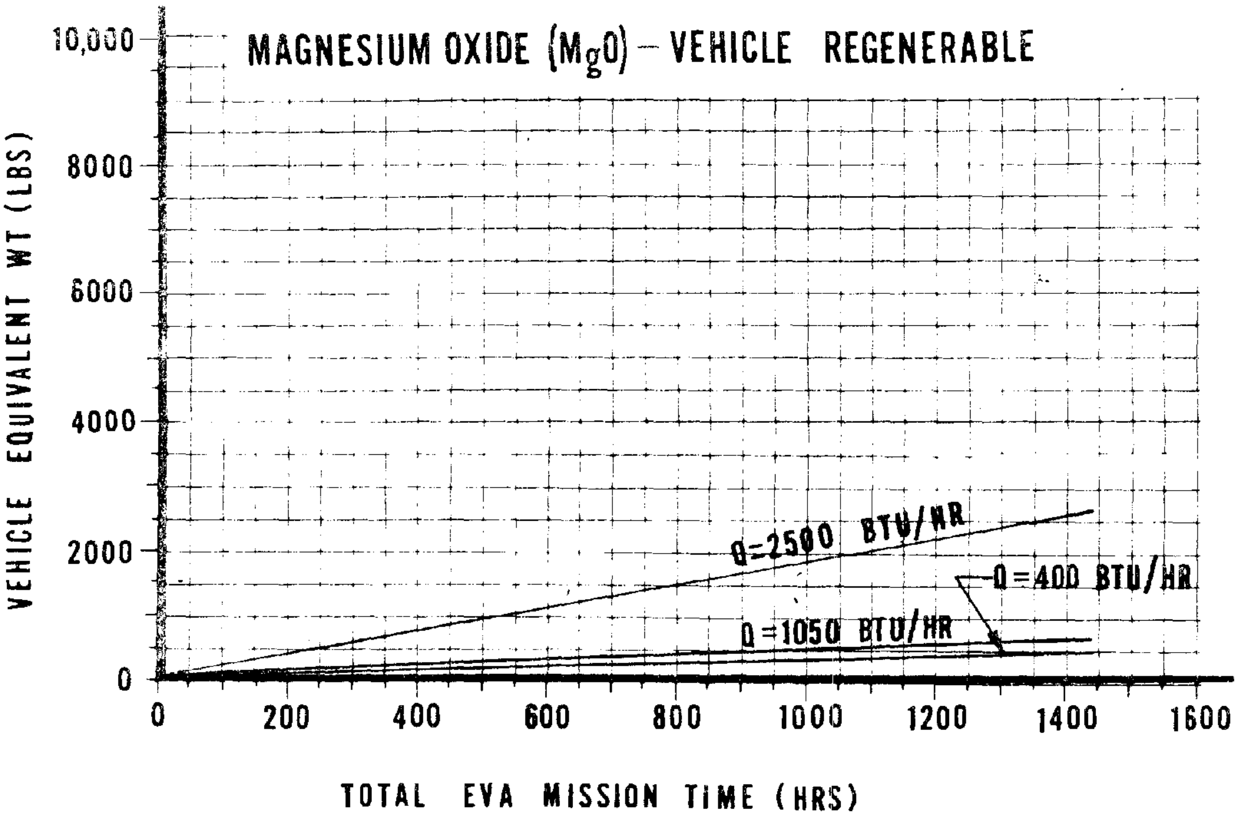
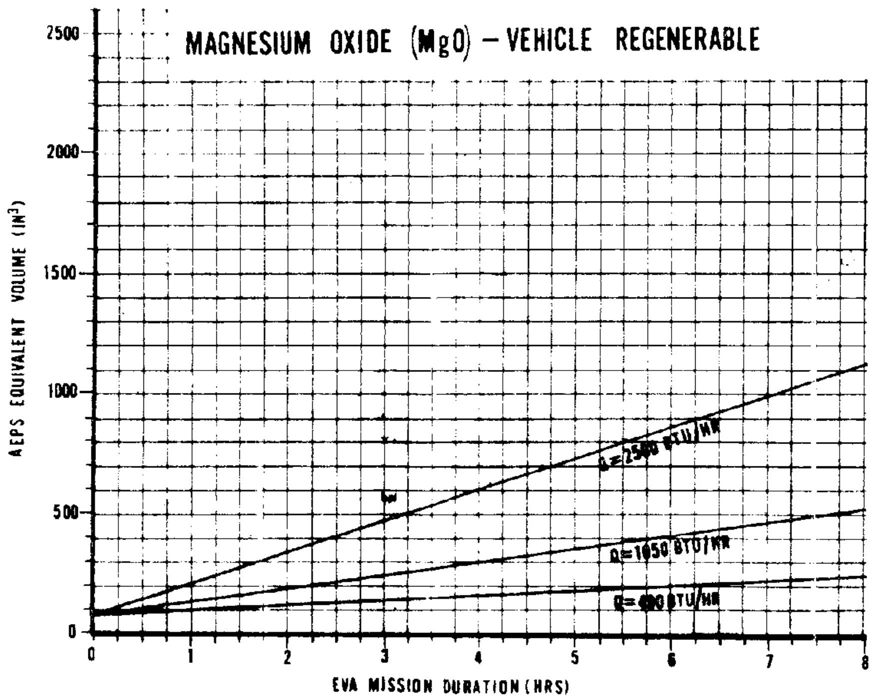
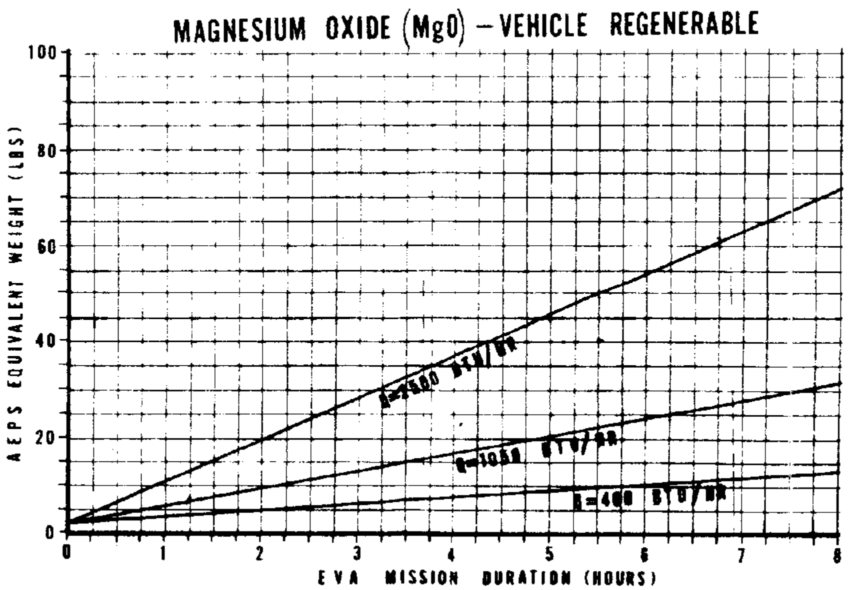
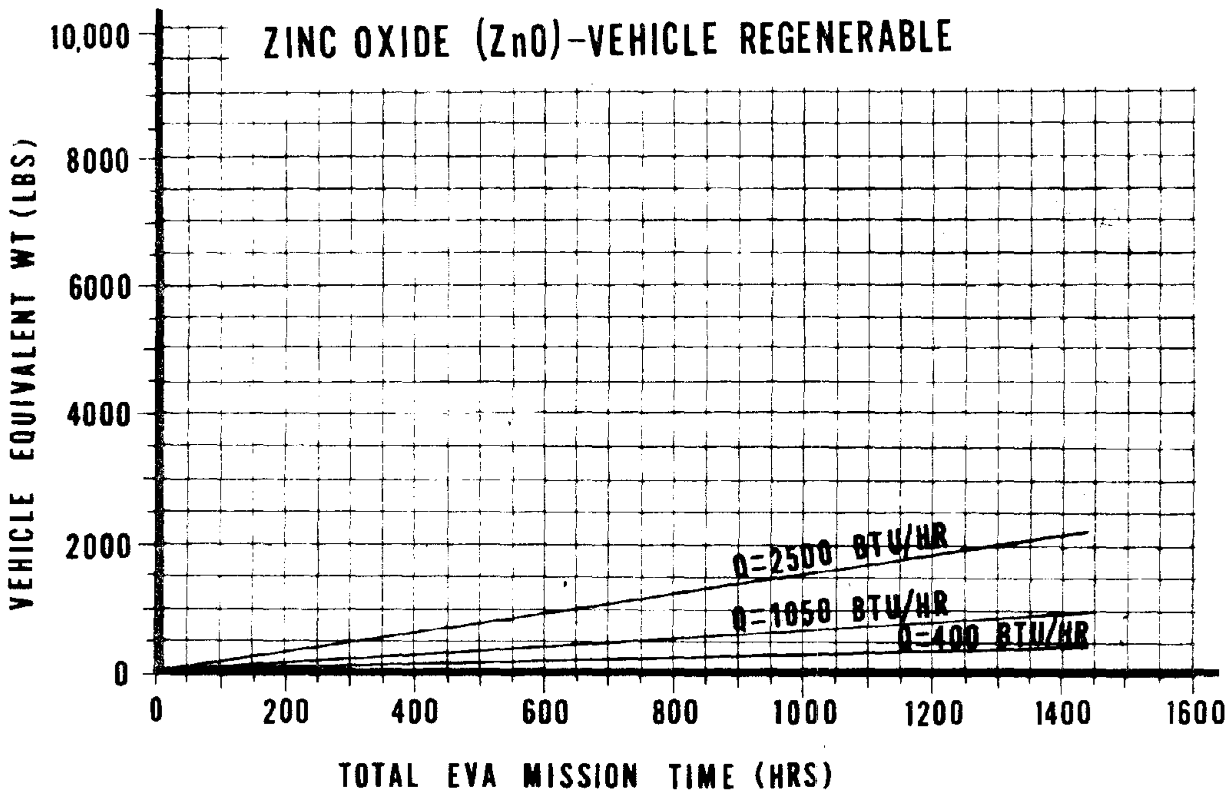


FIGURE 4–24. METALLIC OXIDE – VEHICLE REGENERABLE

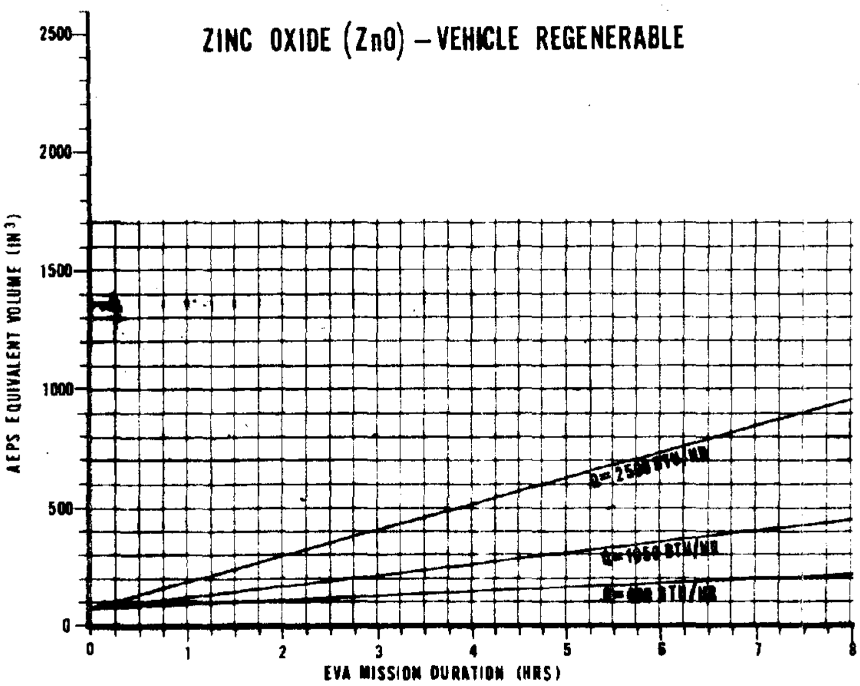

MAGNESIUM OXIDE (MgO) – VEHICLE REGENERABLE
VEHICLE EQUIVALENT WT (LBS)
10,000
8000
6000
4000
2000
0
200
400
600
800
1000
1200
1400
1600
Q=2500 BTU/HR
Q=400 BTU/HR
Q=1050 BTU/HR
TOTAL EVA MISSION TIME (HRS)

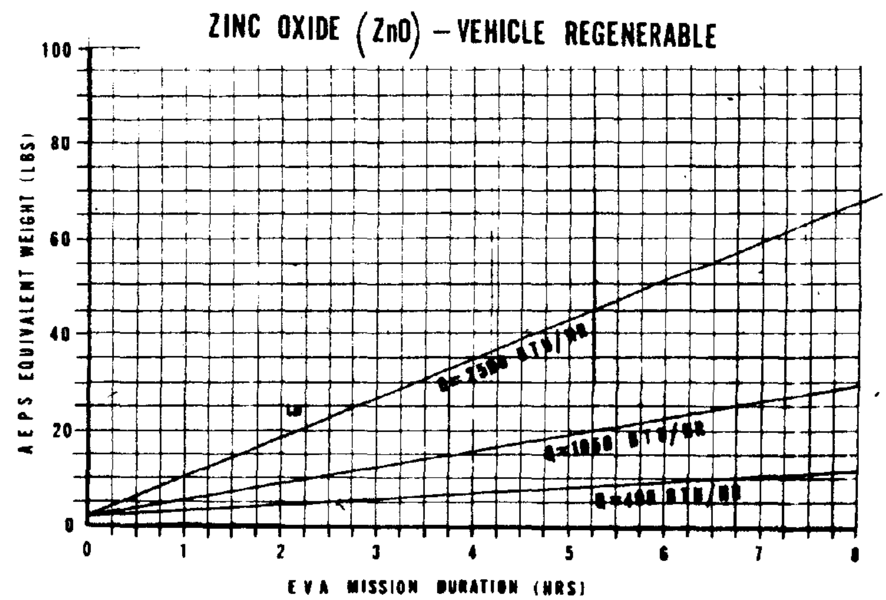

MAGNESIUM OXIDE (MgO) – VEHICLE REGENERABLE
AEPS EQUIVALENT VOLUME (IN³)
2500
2000
1500
1000
500
0
Q=2500 BTU/HR
Q=1050 BTU/HR
BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


MAGNESIUM OXIDE (MgO) – VEHICLE REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
100
80
60
40
20
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HOURS)



ZINC OXIDE (ZnO)-VEHICLE REGENERABLE
VEHICLE EQUIVALENT WT (LBS)
10,000
8000
6000
4000
2000
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)


ZINC OXIDE (ZnO) – VEHICLE REGENERABLE
AEPS EQUIVALENT VOLUME (IN³)
2500
2000
1500
1000
500
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


ZINC OXIDE (ZnO) – VEHICLE REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
100
80
60
40
20
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)

CONCEPTS 6 & 7 - METALLIC OXIDE (AEPS REGENERABLE)

A variation of the metallic oxide concept considers a cyclic or AEPS regenerable configuration. Two beds, similar in design to that described for the vehicle regenerable system, are provided, each containing electrical elements for regeneration and a cooling loop to cool the regenerated bed and maintain temperature control during operation.

A timer is provided to sequence the vent loop and coolant loop valves to allow the vent loop and coolant loop to flow to the on stream bed and to heat and expose to space vacuum the regenerating bed.

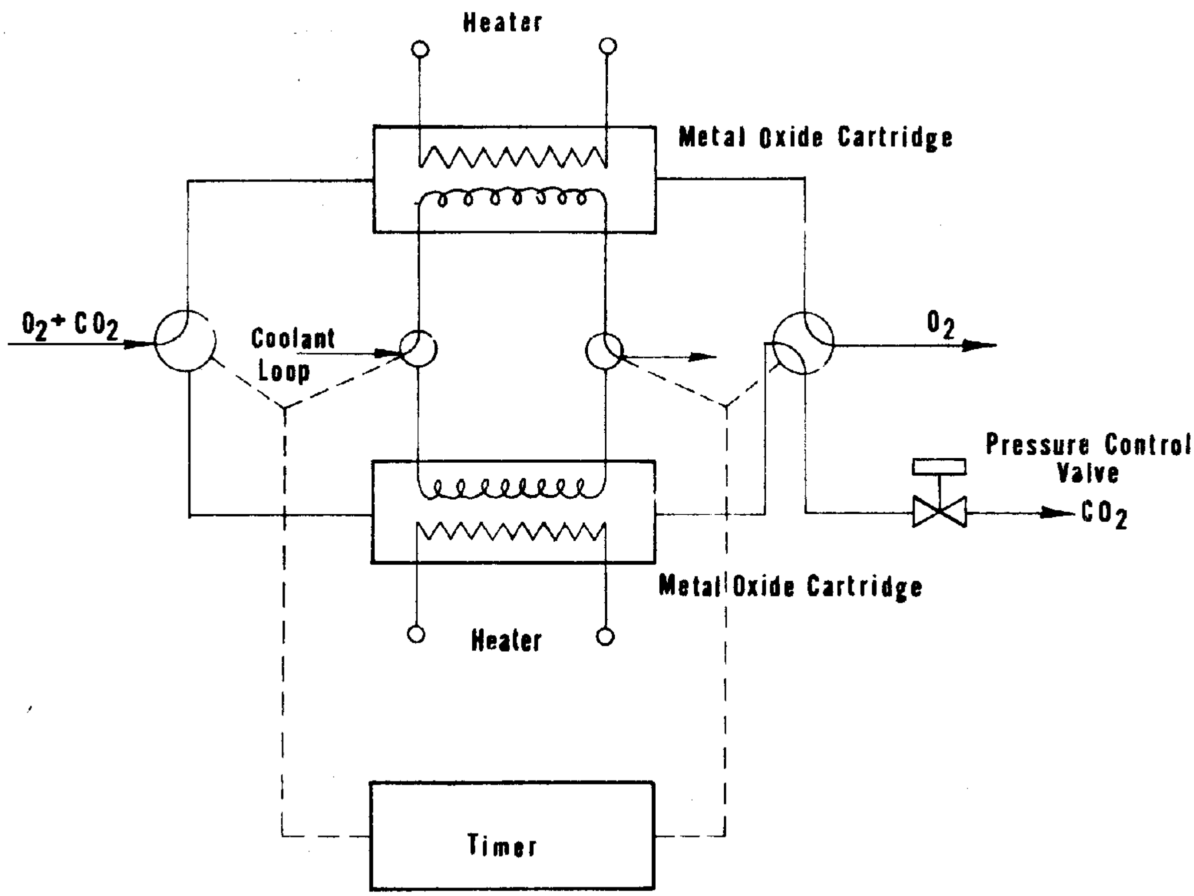
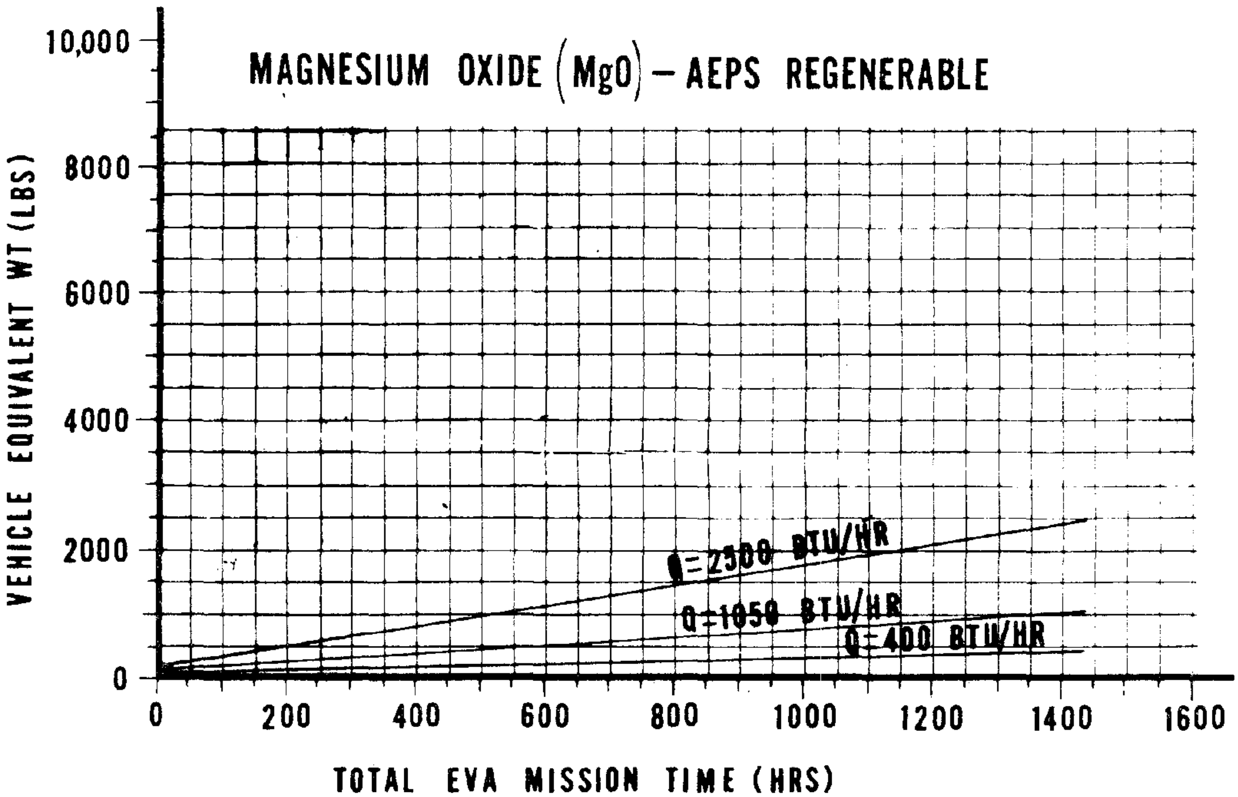
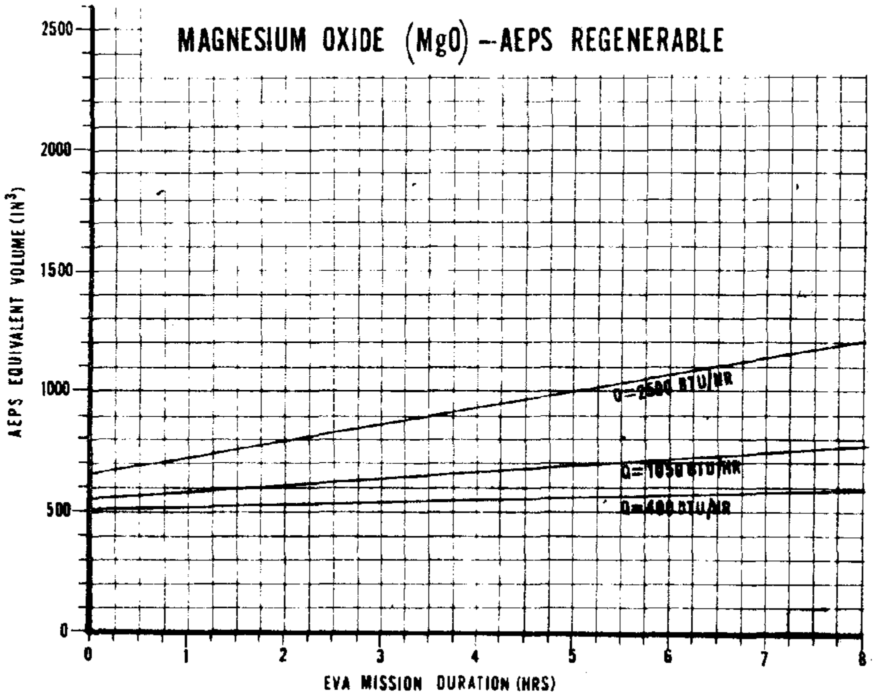
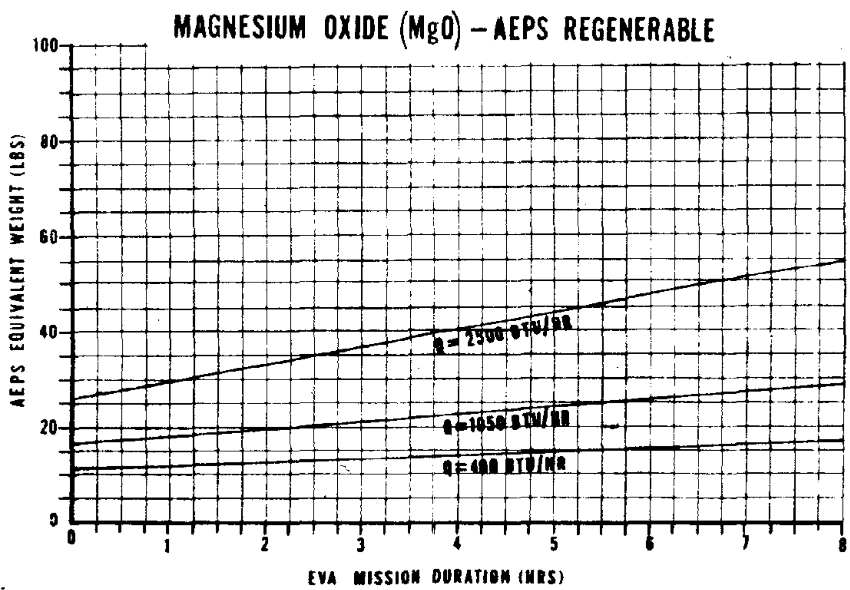


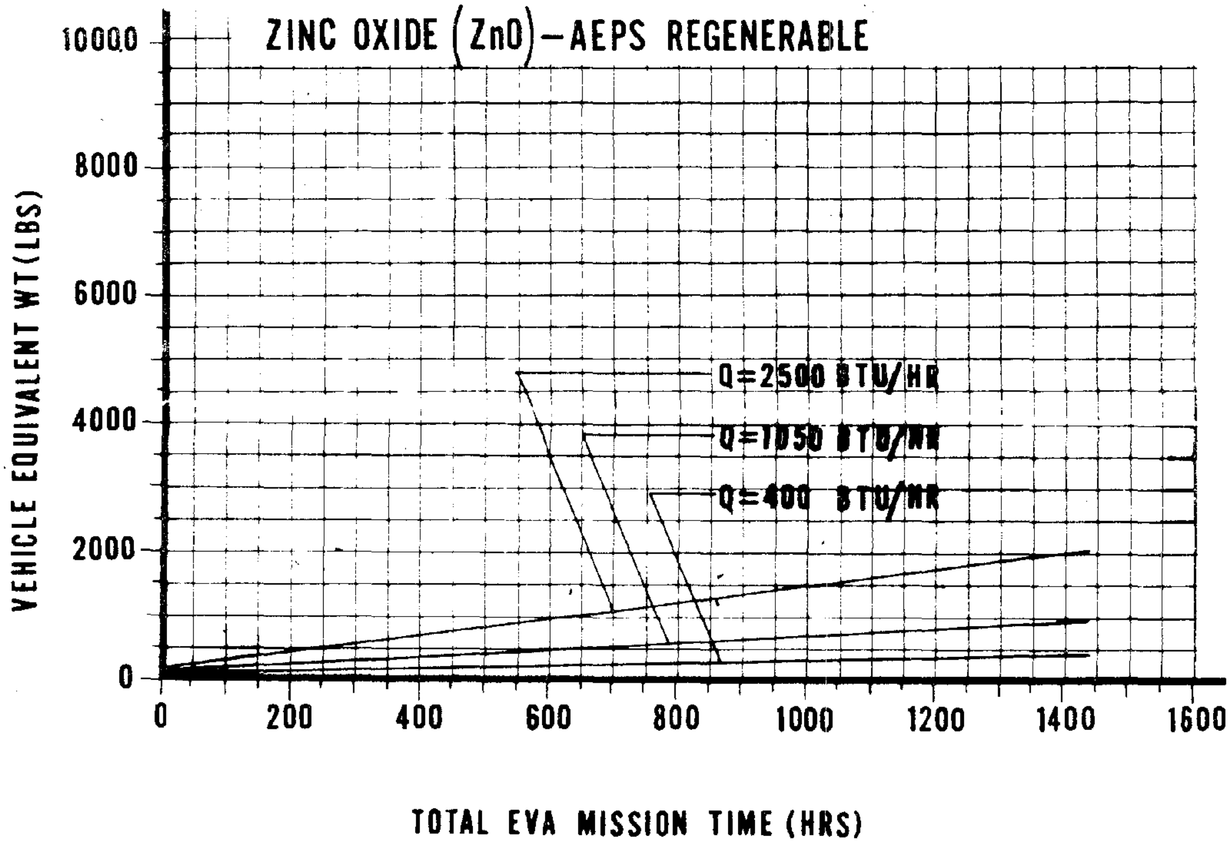
FIGURE 4–25. METALLIC OXIDE – AEPS REGENERABLE



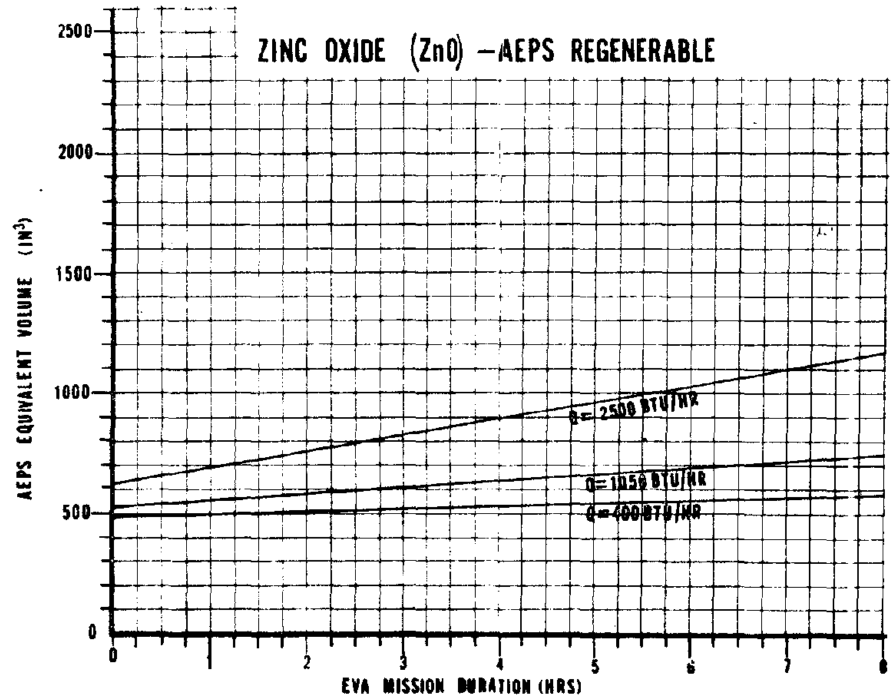
MAGNESIUM OXIDE (MgO) – AEPS REGENERABLE
10,000
8000
6000
4000
2000
0
VEHICLE EQUIVALENT WT (LBS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)

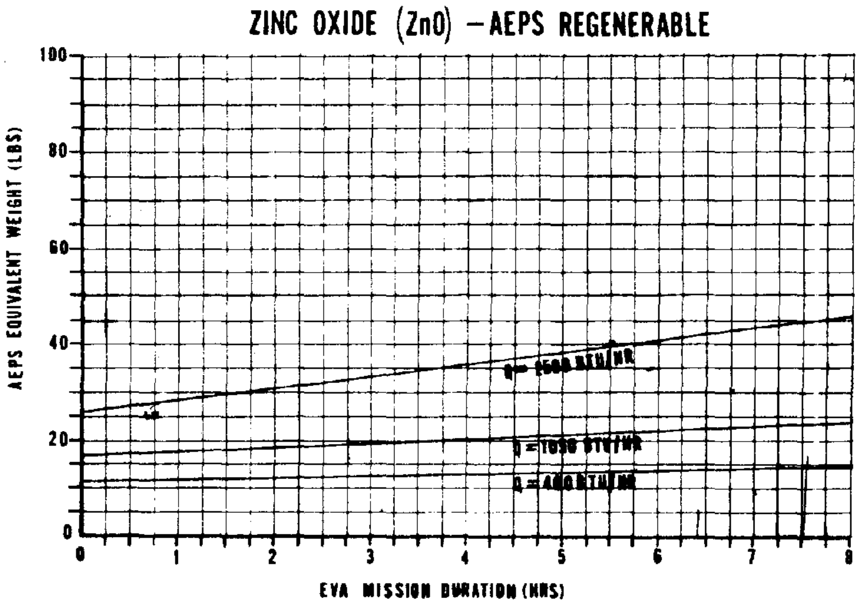

MAGNESIUM OXIDE (MgO) – AEPS REGENERABLE
AEPS EQUIVALENT VOLUME (IN³)
2500
2000
1500
1000
500
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


MAGNESIUM OXIDE (MgO) – AEPS REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
100
80
60
40
20
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)



ZINC OXIDE (ZnO)–AEPS REGENERABLE
VEHICLE EQUIVALENT WT (LBS)
10000
8000
6000
4000
2000
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)


ZINC OXIDE (ZnO) —AEPS REGENERABLE
AEPS EQUIVALENT VOLUME (IN³)
2500
2000
1500
1000
500
0
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


ZINC OXIDE (ZnO) —AEPS REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)

CONCEPT 8 - SOLID AMINE - AEPS REGENERABLE

An inert carrier is utilized to provide a stable amine adsorbent bed in this concept. The regenerable solid amine is packaged within the flow passages of a plate-fin matrix similar in design to an extended surface compact heat exchanger. Alternate flow passages contain adsorbing and desorbing material with the unique feature of an isothermal process. Energy released from the adsorbing passages is transferred by conduction through the metal matrix to the desorbing material to supply the requirements of the endothermic desorption. This concept neither imposes a thermal load on the AEPS nor requires energy for regeneration. A timer and valving is provided to cycle the packed beds from the on-line adsorb to the space vacuum desorb cycle.

Further development is required in the adsorbent, however, to find application within the AEPS system. Current materials possess an affinity for water that would excessively dehumidify the ventilation loop. This loss of water vapor could not only cause astronaut discomfort, but may also reduce the adsorbent's capacity for CO_2 and thus result in poor CO_2 control. This problem has been recognized and solutions have been proposed to alter the amine and to minimize its affinity for water.

The following curves are based on a 2% CO_2 capacity of the solid amine plus the inert carrier.

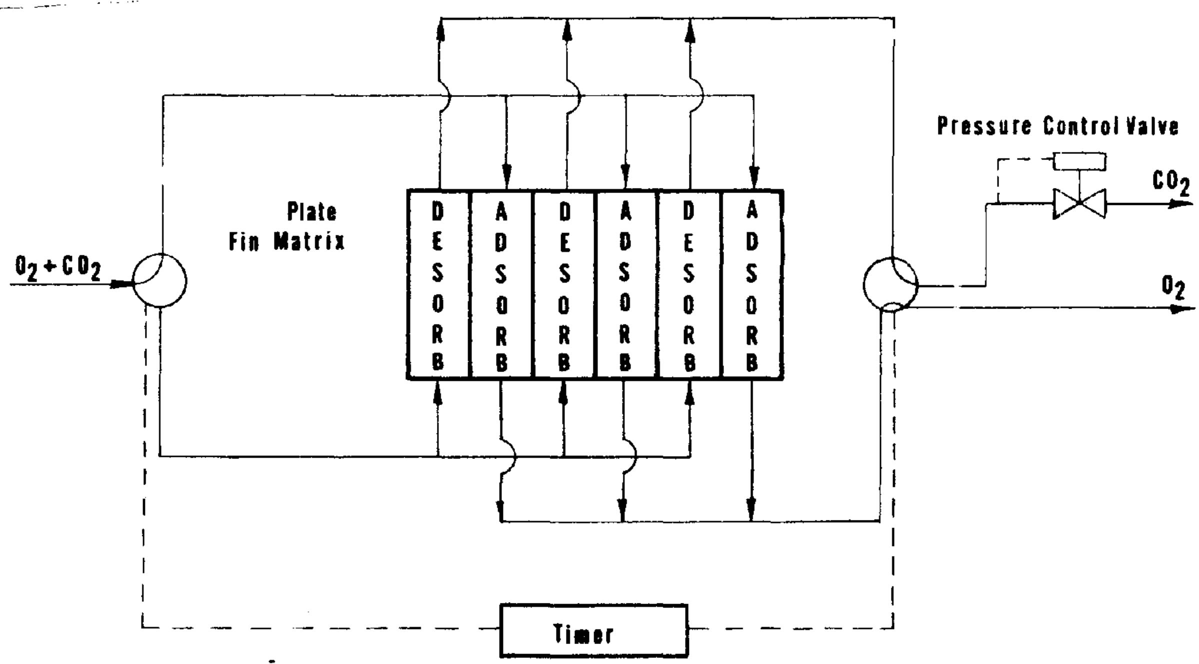
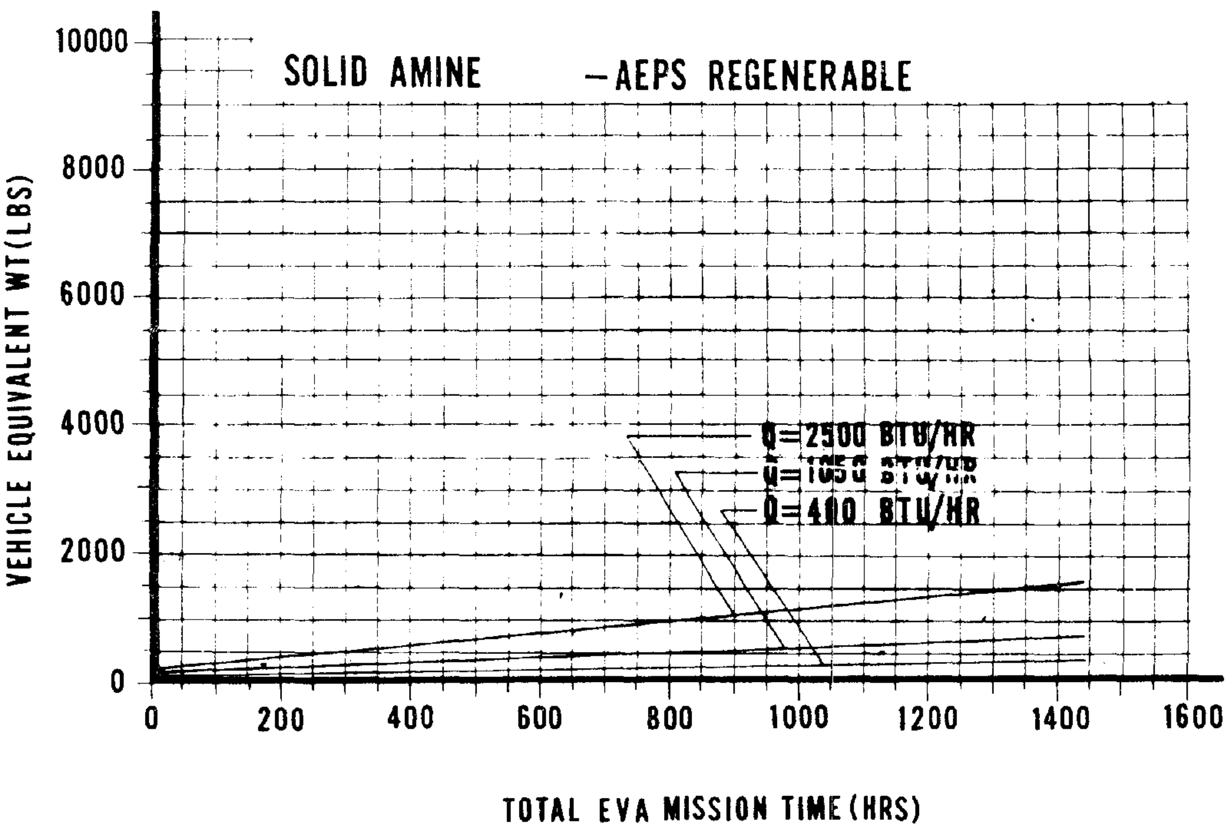
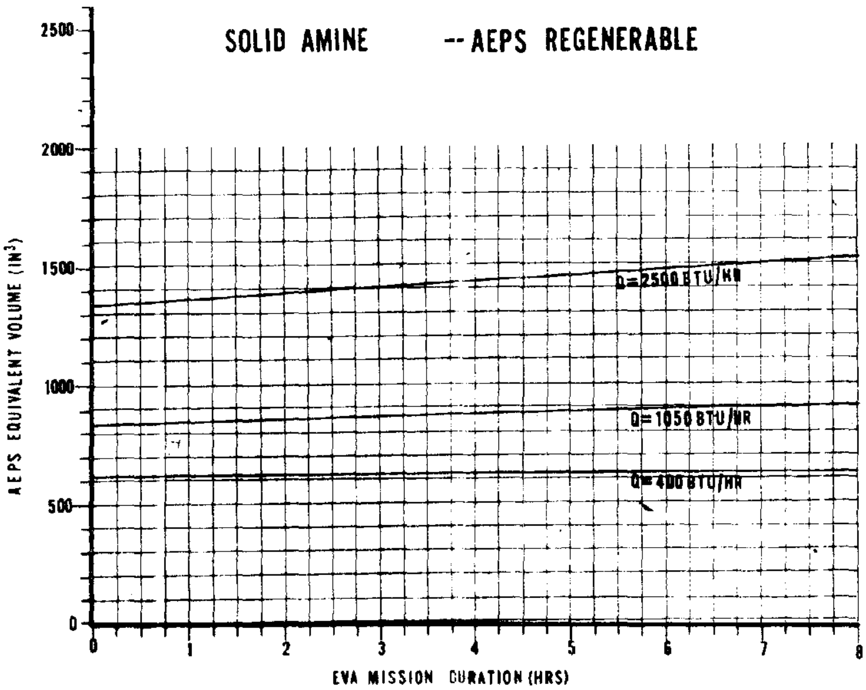
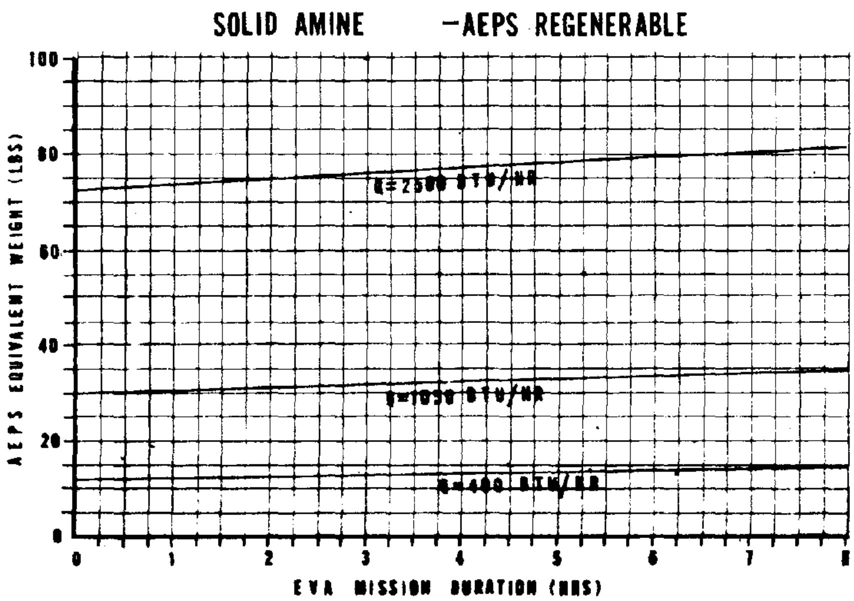


FIGURE 4–26. SOLID AMINE – AEPS REGENERABLE


SOLID AMINE — AEPS REGENERABLE
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
VEHICLE EQUIVALENT WT(LBS)
TOTAL EVA MISSION TIME(HRS)
0
2000
4000
6000
8000
10000
200
400
600
800
1000
1200
1400
1600


SOLID AMINE --AEPS REGENERABLE
2500
2000
1500
1000
500
0
AEPS EQUIVALENT VOLUME (IN³)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


SOLID AMINE -AEPS REGENERABLE
100
80
60
40
20
0
AEPS EQUIVALENT WEIGHT (LBS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)

CONCEPT 9 - LIQUID AMINE SORBENT

Ventilation flow from the astronaut flows to a gas/liquid contactor where intimate contact is made with a recirculating amine solution. Carbon dioxide is absorbed from the gas stream by the solution which passes to a rotary separator and then to the regeneration circuit. Solution free oxygen discharging from the separator passes through a backup sorbent bed to the thermal/humidity control subsystem.

Within the regeneration circuit, the solution is heated to drive off the CO_2 which is removed in a second gas/liquid separator and dumped to space vacuum. A regenerative heat exchanger is provided to minimize regeneration energy requirements and a final cooler to condition the solution for the adsorb cycle.

Two areas of development are required for concept operability: (1) minimize water absorption to prevent excessive dehumidification similar to the solid amine; and (2) find a suitable solvent/carrier for the amine. The viscosity of the pure amines is quite high and would have a detrimental effect on pumping power and gas/liquid contacting efficiency. Although water is an excellent solvent for the amine, it is preferentially evaporated from the solution before the CO_2 is desorbed. This imposes high regeneration thermal loads and adds the requirement for a water condenser and condensate return system. This concept has assumed that the desired low viscosity-low vapor pressure solvent will be available for system development.

The following curves are based on a PEI solution having a utilization efficiency of 75% at a metabolic load of 1050 BTU/hr.

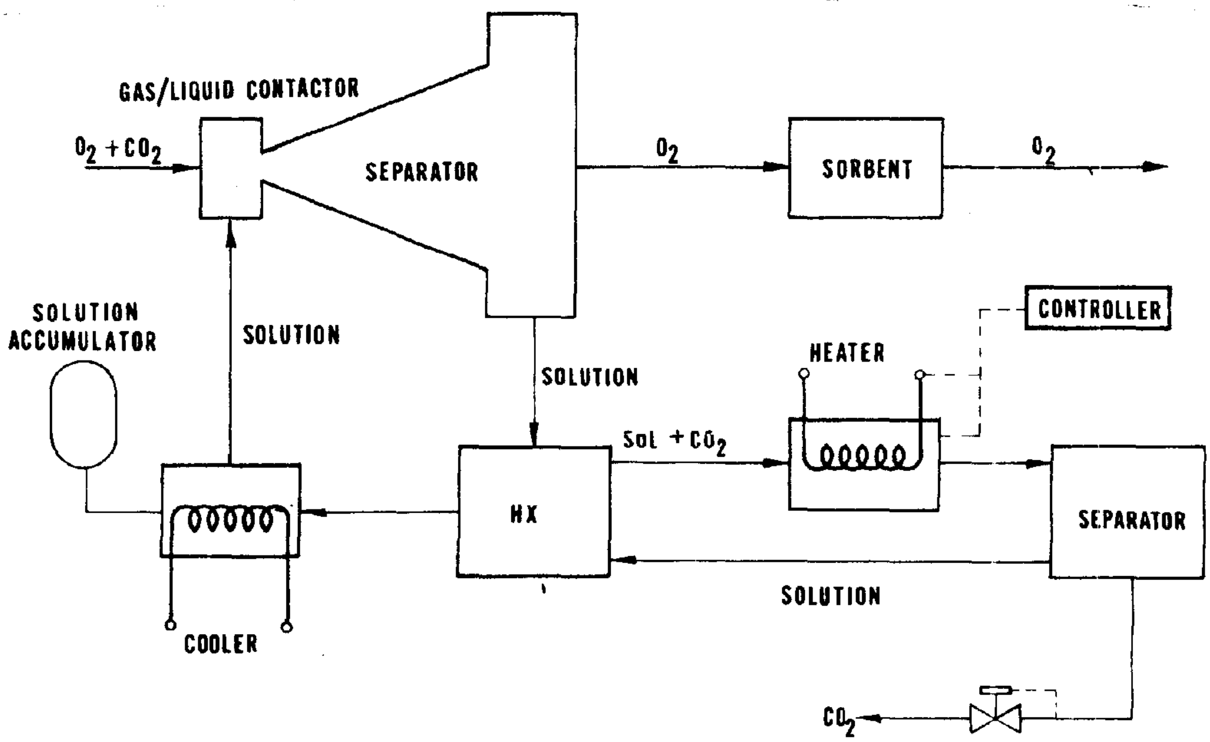
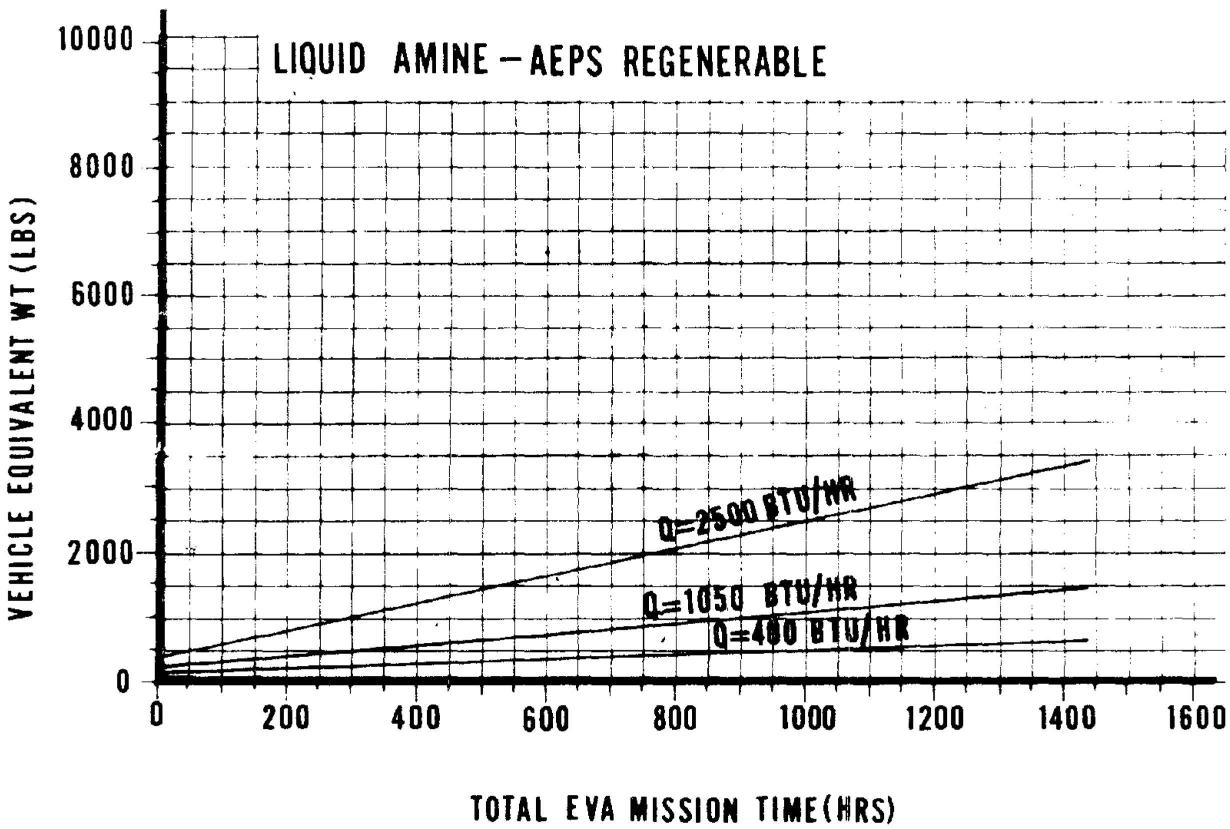
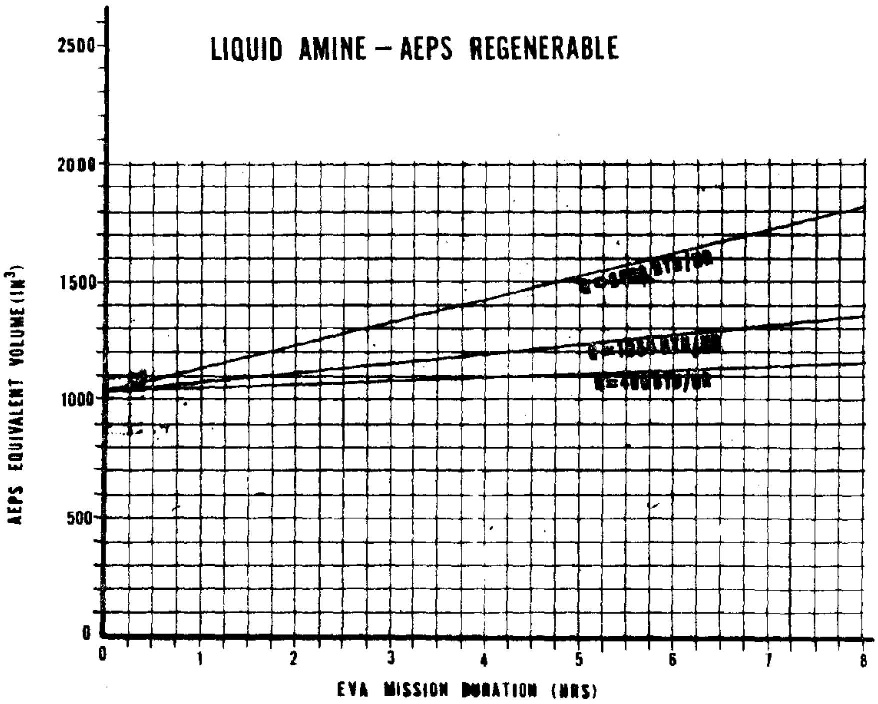
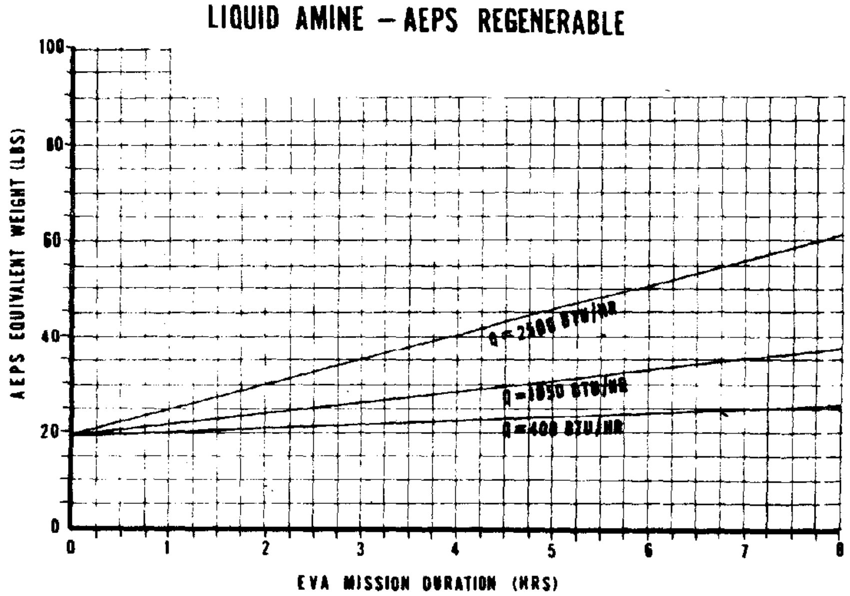


FIGURE 4–27. LIQUID AMINE SORBENT



LIQUID AMINE – AEPS REGENERABLE
VEHICLE EQUIVALENT WT (LBS)
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
1200
1400
1600
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
TOTAL EVA MISSION TIME(HRS)


LIQUID AMINE – AEPS REGENERABLE
AEPS EQUIVALENT VOLUME (IN^3)
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


LIQUID AMINE – AEPS REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR
EVA MISSION DURATION (HRS)

CONCEPT 10 - SOLID ELECTROLYTE

In the solid electrolyte concept, CO_2 is fed from an accumulator to the process system. The CO_2 concentration and compression stage has not been included here and could be accomplished by any of the selected regenerable systems. Because the CO_2 flow is insufficient to supply total metabolic oxygen and leakage requirements, water is added to the solid electrolyte reactor feed at the humidifier. Water flow is governed by oxygen demand. Operating at 1800°F, the solid electrolyte passes ionic oxygen from the cathode to the anode forming molecular oxygen. This product is then cooled for delivery. Hydrogen, carbon monoxide and other trace residuals pass from the cathode compartment to the H_2 separator. Hydrogen is dumped overboard while the CO passes to a nickel catalyst reactor where the following reaction occurs at 1000°F

$$2CO \xrightarrow{Ni} CO_2 + C$$

A regenerative heat exchanger thermally conditions the reactor feed with the product CO_2 which is recycled to the humidifier inlet. Solid carbon must be periodically removed from the reactor.

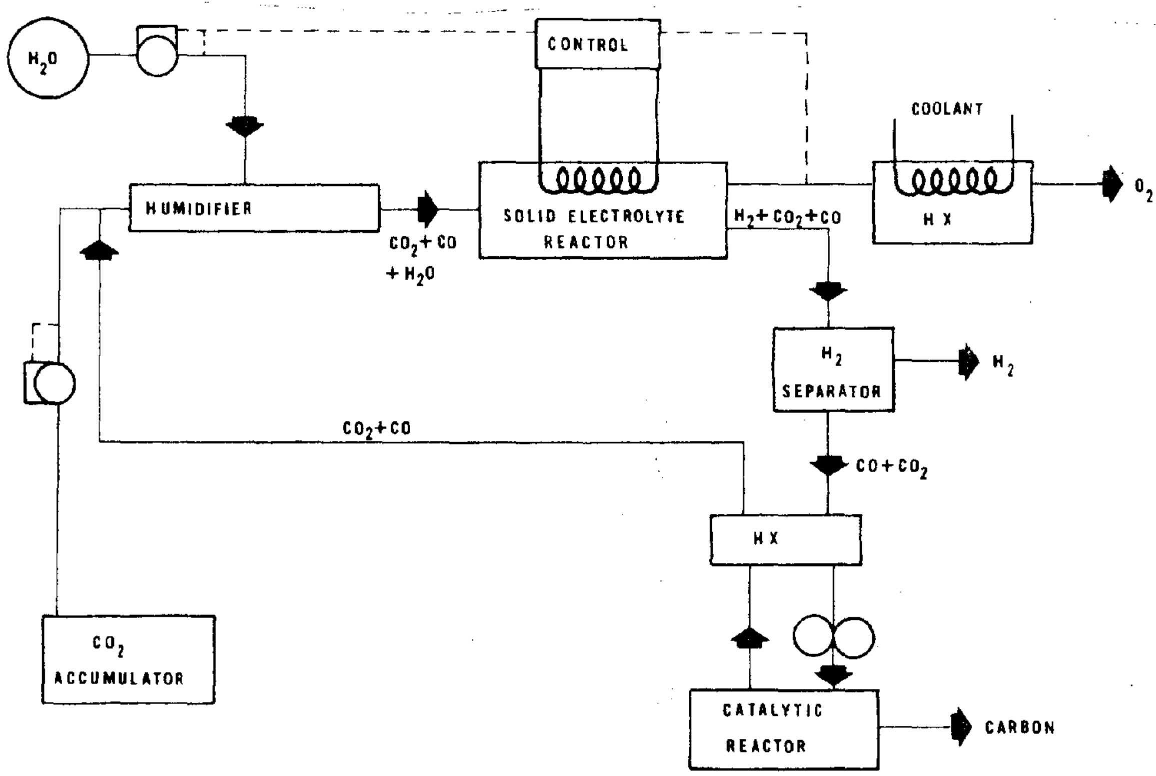
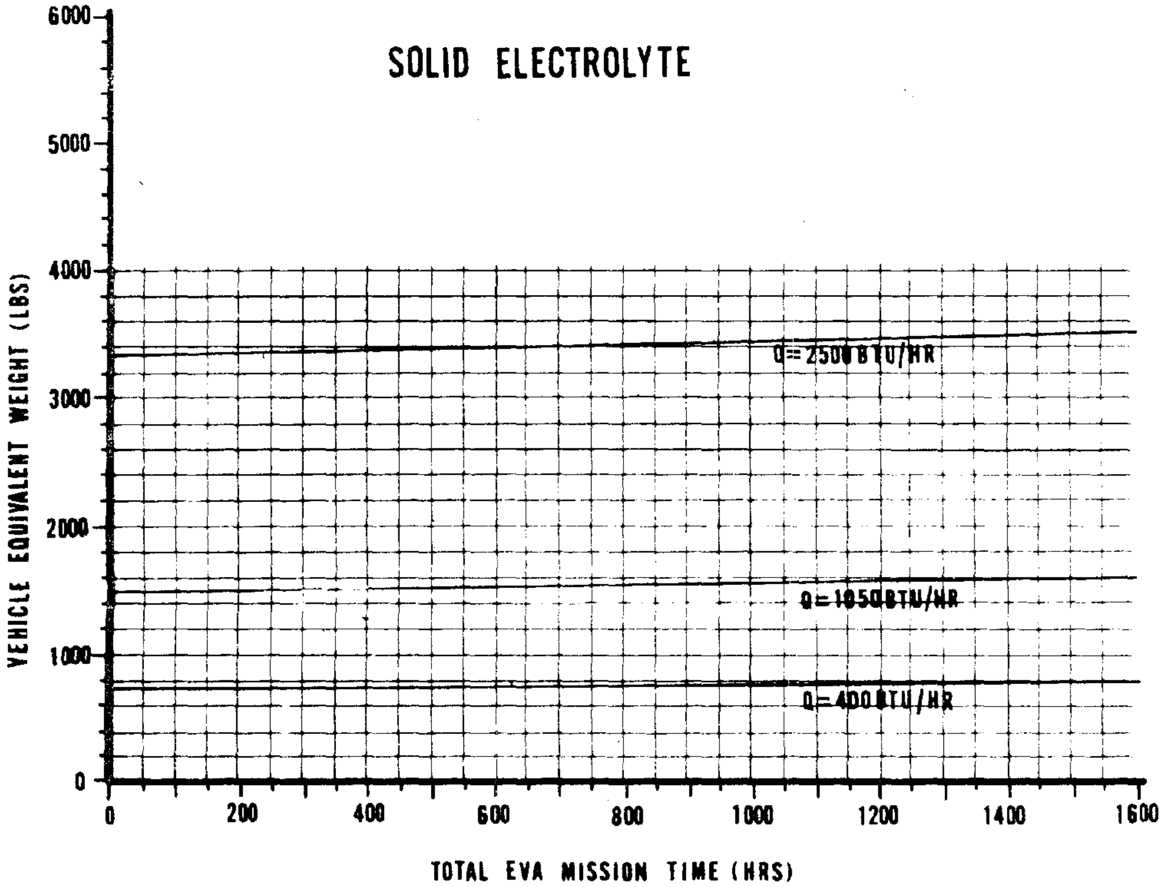
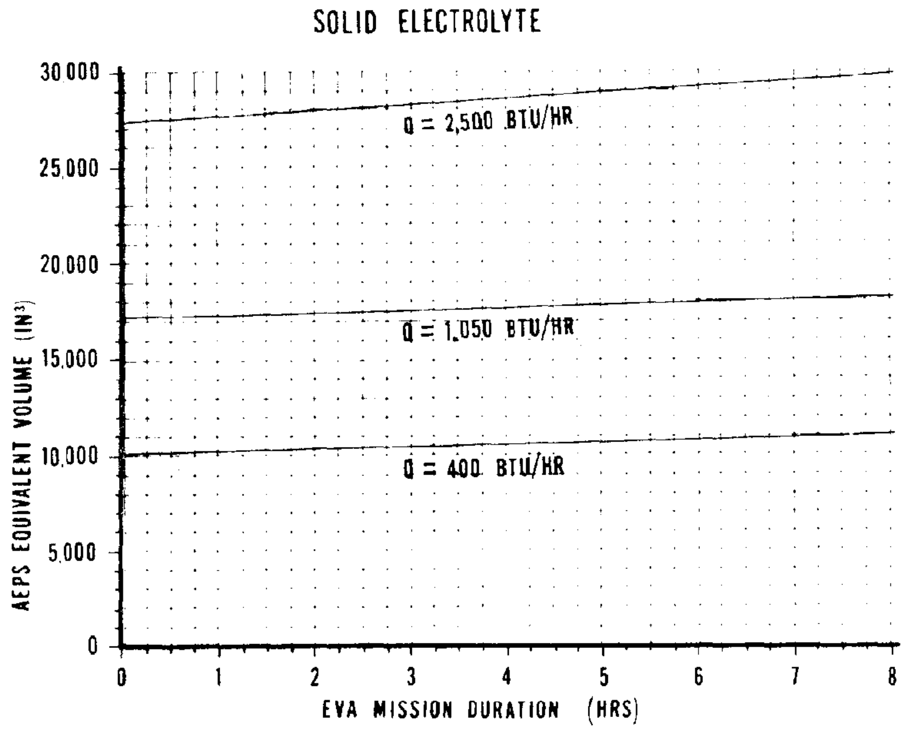
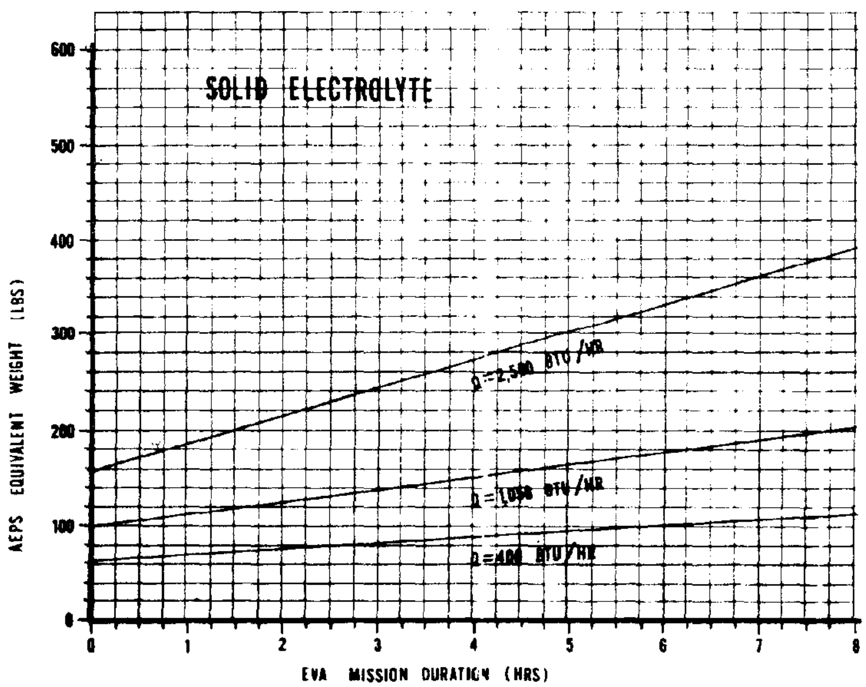


FIGURE 4–28. SOLID ELECTROLYTE


SOLID ELECTROLYTE
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)
0
1000
2000
3000
4000
5000
6000
200
400
600
800
1000
1200
1400
1600


SOLID ELECTROLYTE
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8


SOLID ELECTROLYTE
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8

CONCEPT 11 - CO_2 REMOVAL & REDUCTION/O_2 GENERATION

Three basic subsystems are integrated into this totally AEPS regenerable concept. A hydrogen depolarized cell consumes hydrogen and oxygen in a water production fuel cell reaction to produce the EMF necessary for CO_2 removal from the ventilation loop. The water vapor electrolysis unit supplies oxygen for metabolic consumption and leakage and hydrogen for operation of the H_2 depolarized cell and the Sabatier reactor. Oxygen is reclaimed as water in the Sabatier reactor according to the following reaction:

$$CO_2 + 4H_2 \longrightarrow 2H_2O + CH_4$$

Vent loop flow from the astronaut enters the H_2 depolarized cell where it picks up the water produced in this unit. CO_2 is removed and is discharged into the hydrogen stream which passes to the Sabatier reactor for CO_2 reduction. A condensing heat exchanger returns product water to an accumulator.

H_2 depolarized cell operation is controlled by the CO_2 sensor through an external rheostat which sets the available EMF to a level required for the CO_2 processing rates. Water vapor is added to the H_2 depolarized cell product stream and is then heated to obtain the proper relative humidity prior to entering the water vapor electrolysis unit. Water vapor is absorbed by the electrolyte in this device, as required, to maintain a desired electrolyte concentration. Oxygen production (and the associated hydrogen production) is determined by the output of the vent loop pressure sensor. A condenser conditions the gas for return to the astronaut and the condensate is returned to the accumulator.

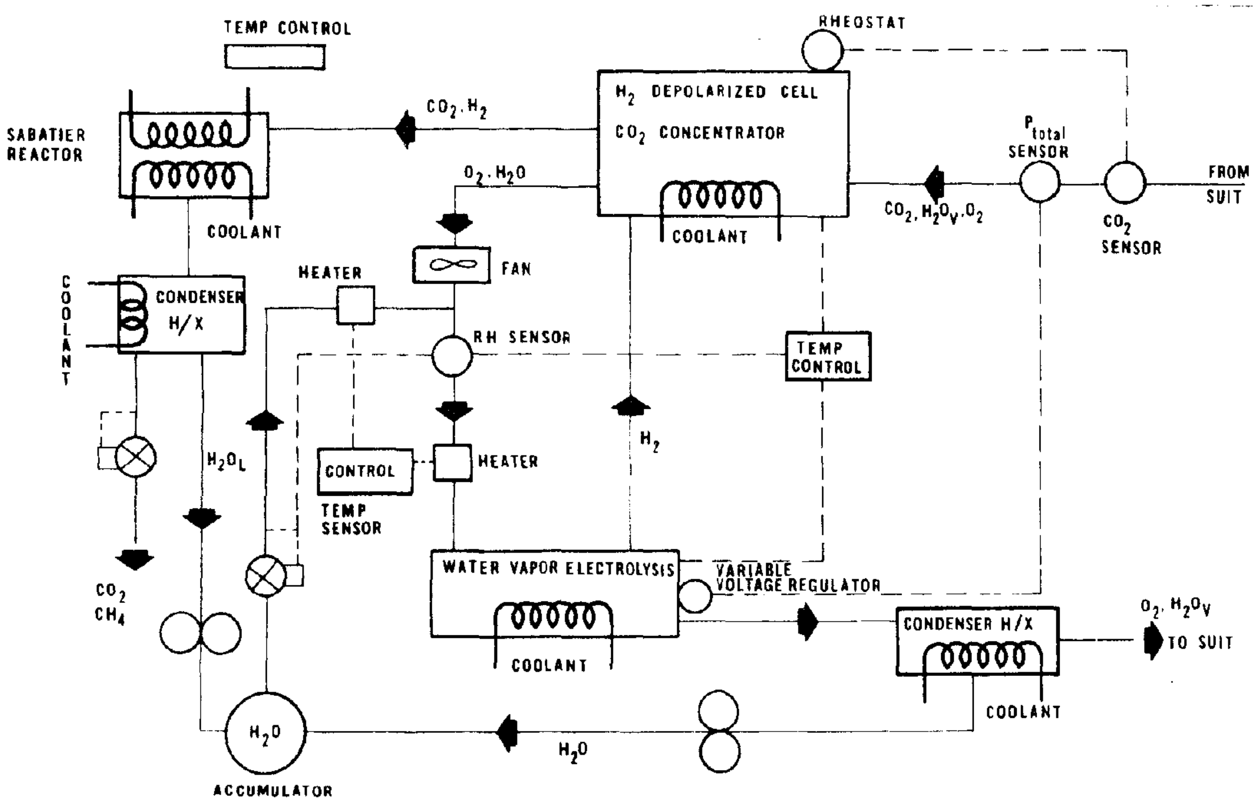
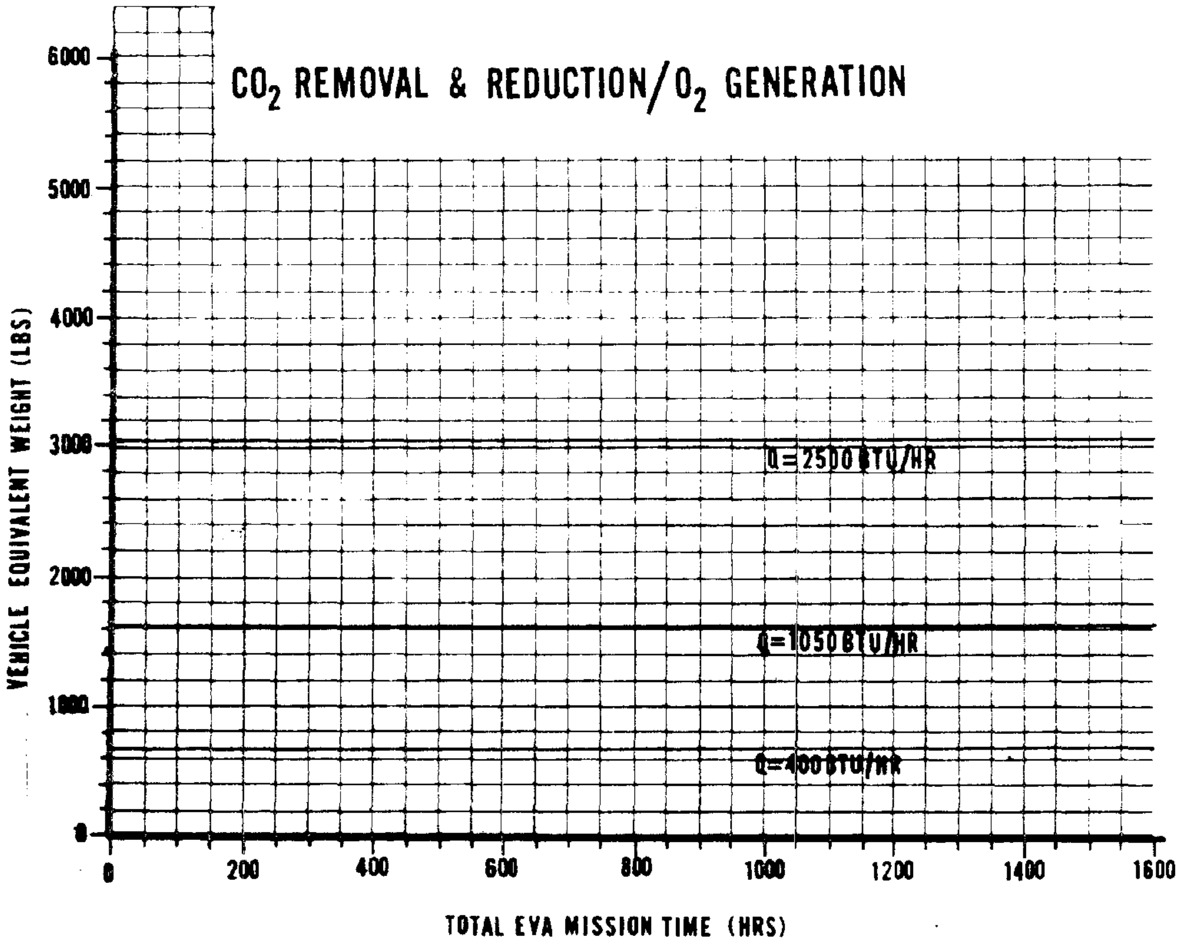
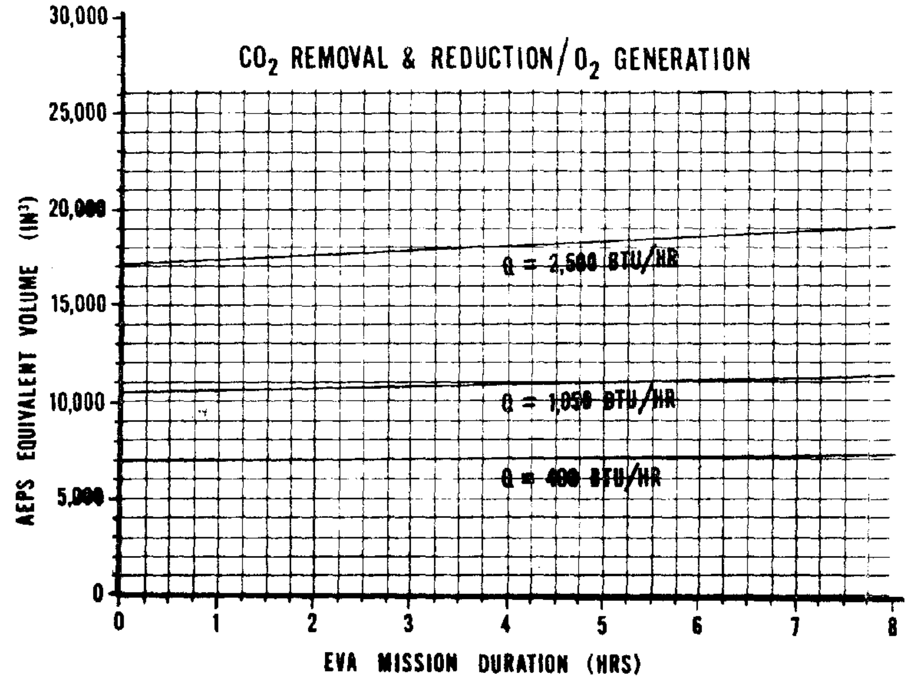


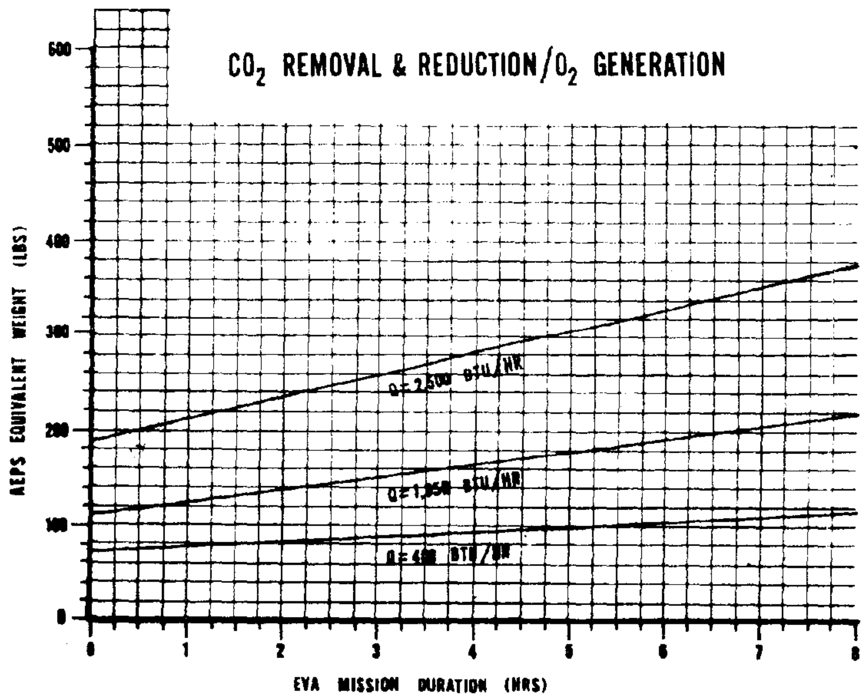
FIGURE 4–29. CO_2 REMOVAL & REDUCTION/O_2 GENERATION



CO_2 REMOVAL & REDUCTION/O_2 GENERATION
6000
5000
4000
3000
2000
1000
0
VEHICLE EQUIVALENT WEIGHT (LBS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)



CO2 REMOVAL & REDUCTION/O2 GENERATION
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)



CO2 REMOVAL & REDUCTION/O2 GENERATION
Q=2,500 BTU/HR
Q=1,050 BTU/HR
Q=400 BTU/HR
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)

CONCEPT 12 - CO_2 REMOVAL & STORAGE/O_2 GENERATION

This concept is identical to the previous one except the Sabatier reactor has been replaced by a CO_2 storage system. Hydrogen is removed in the platinum tube separator and dumped overboard and water vapor is removed in the condenser. CO_2 is stored in the accumulator for eventual reduction in the vehicle.

This concept was evaluated to determine the feasibility of eliminating the AEPS CO_2 reduction system without dumping the CO_2 overboard.

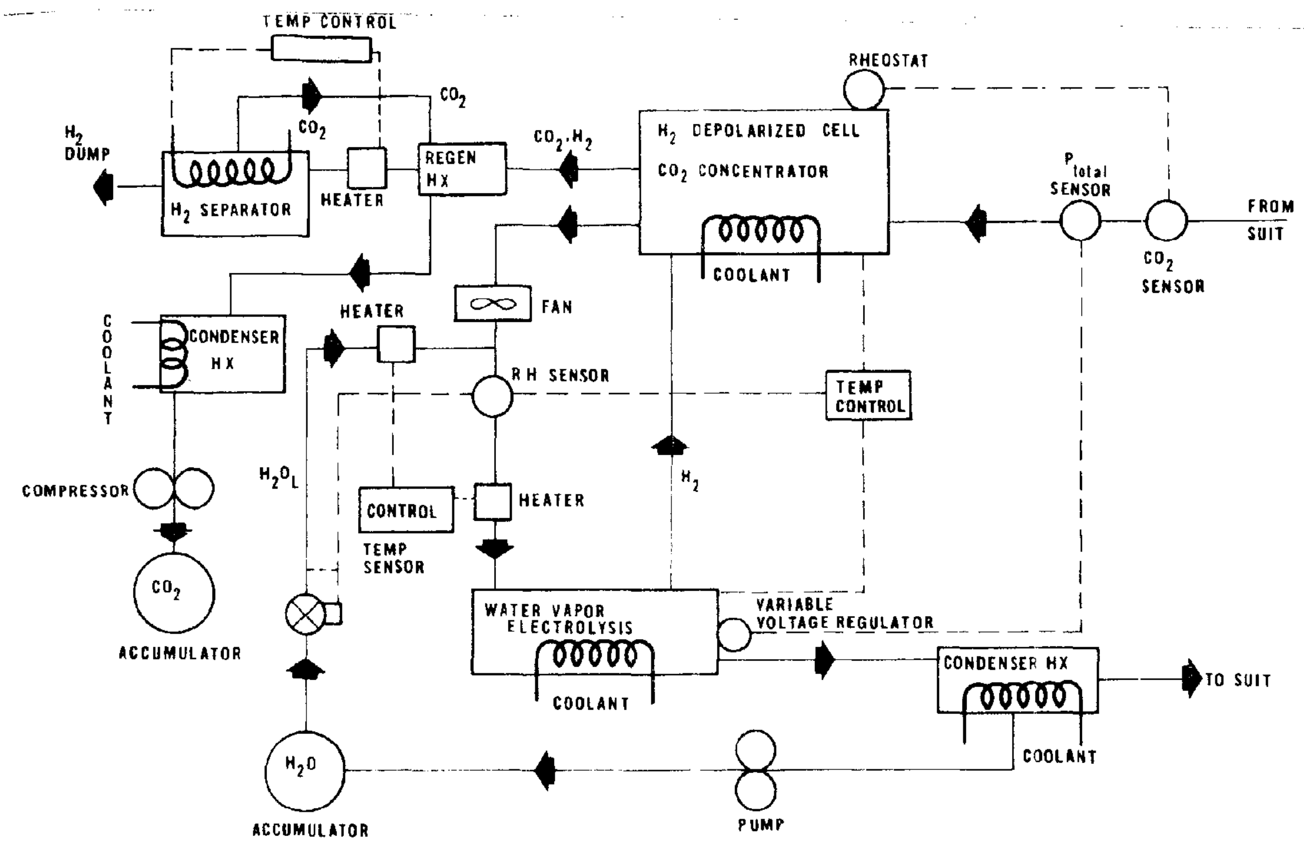
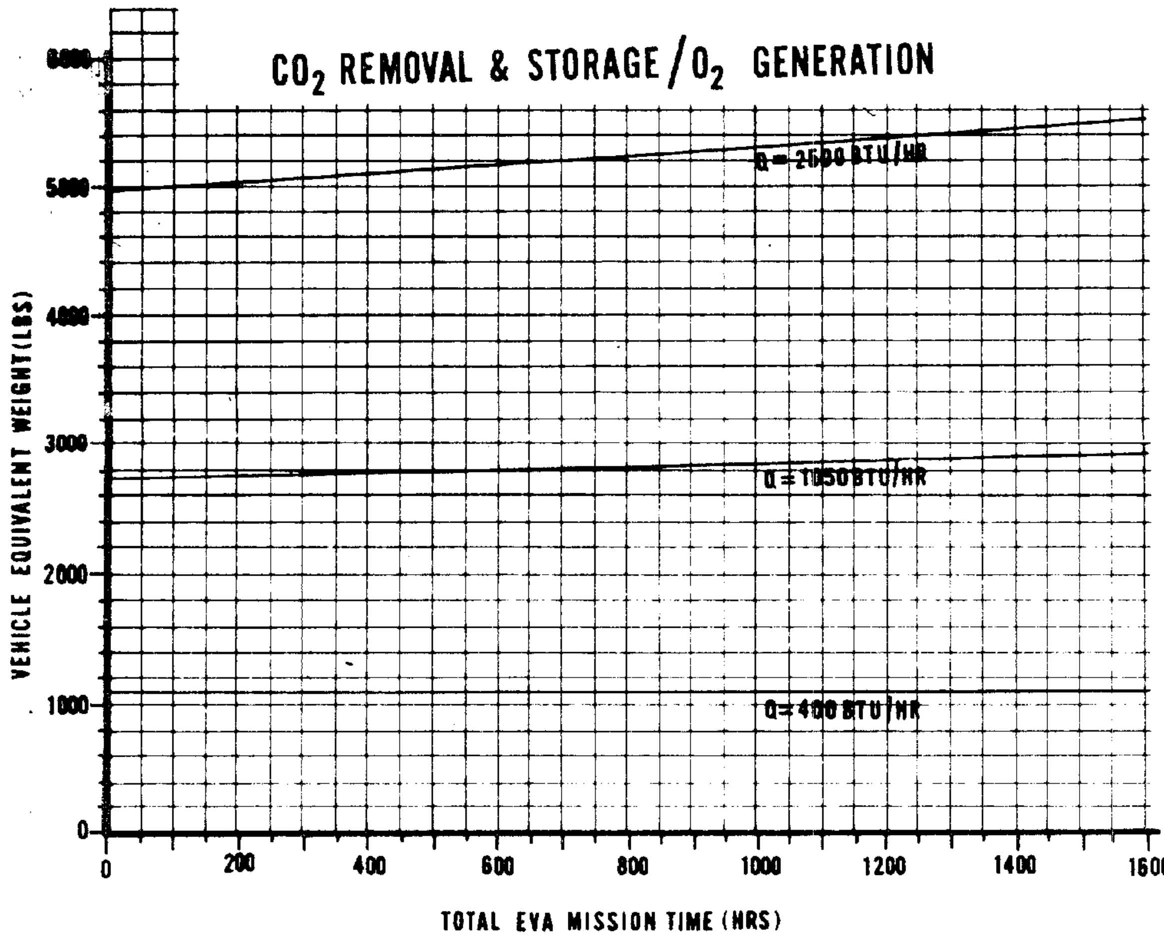
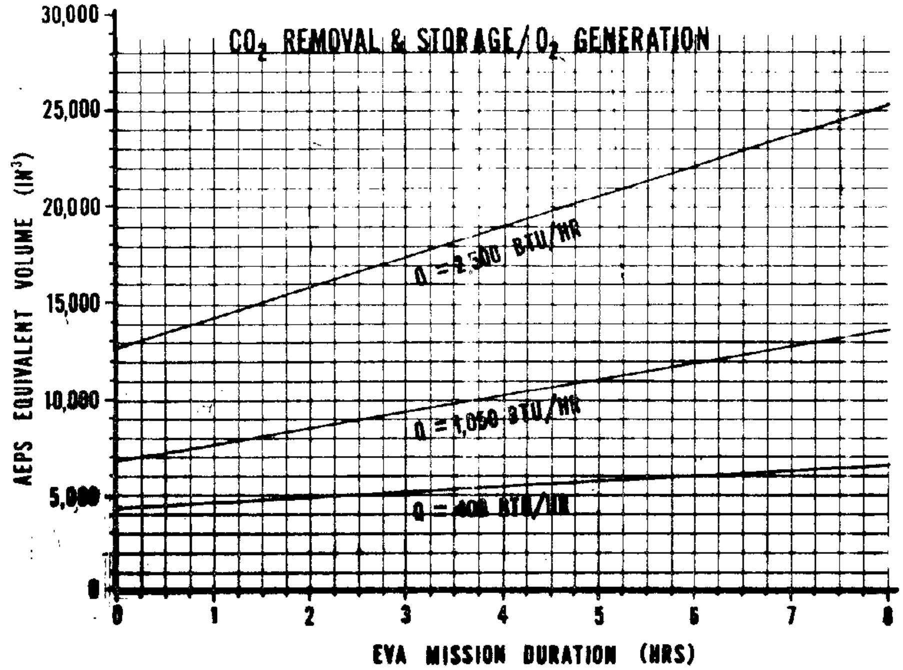


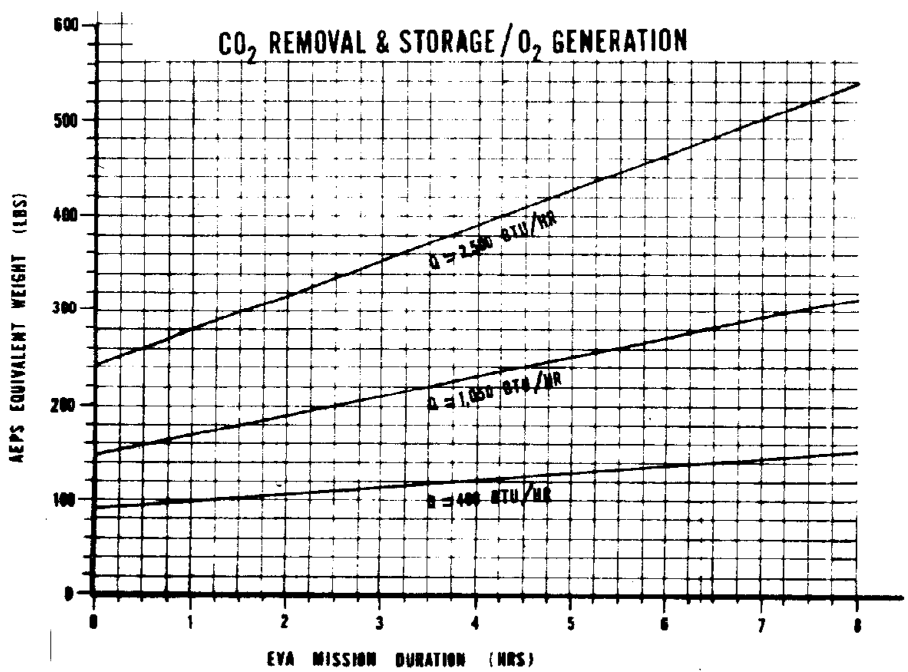
FIGURE 4–30. CO_2 REMOVAL & STORAGE/O_2 GENERATION



CO_2 REMOVAL & STORAGE / O_2 GENERATION
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR
0
1000
2000
3000
4000
5000
6000
0
200
400
600
800
1000
1200
1400
1600



CO_2 REMOVAL & STORAGE/O_2 GENERATION
30,000
25,000
20,000
15,000
10,000
5,000
0
AEPS EQUIVALENT VOLUME (IN^3)
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)



CO_2 REMOVAL & STORAGE/O_2 GENERATION
600
500
400
300
200
100
0
AEPS EQUIVALENT WEIGHT (LBS)
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)

CONCEPT 13 - CO_2 REMOVAL & REDUCTION/O_2 SUPPLY

The hydrogen depolarized cell removes CO_2 from the AEPS inlet vent loop which then passes to the thermal/humidity control heat exchanger and returns to the astronaut. Oxygen is supplied from a high pressure bottle.

Hydrogen for H_2 depolarized cell operation and CO_2 reduction is supplied by the vehicle and stored in the AEPS as high pressure gas. The CO_2/H_2 effluent from the H_2 depolarized cell passes to the Sabatier reactor where it is catalytically reacted to form CH_4 and H_2O. Water from this process and from the humidity control subsystem is stored in an accumulator for eventual vehicle or AEPS use.

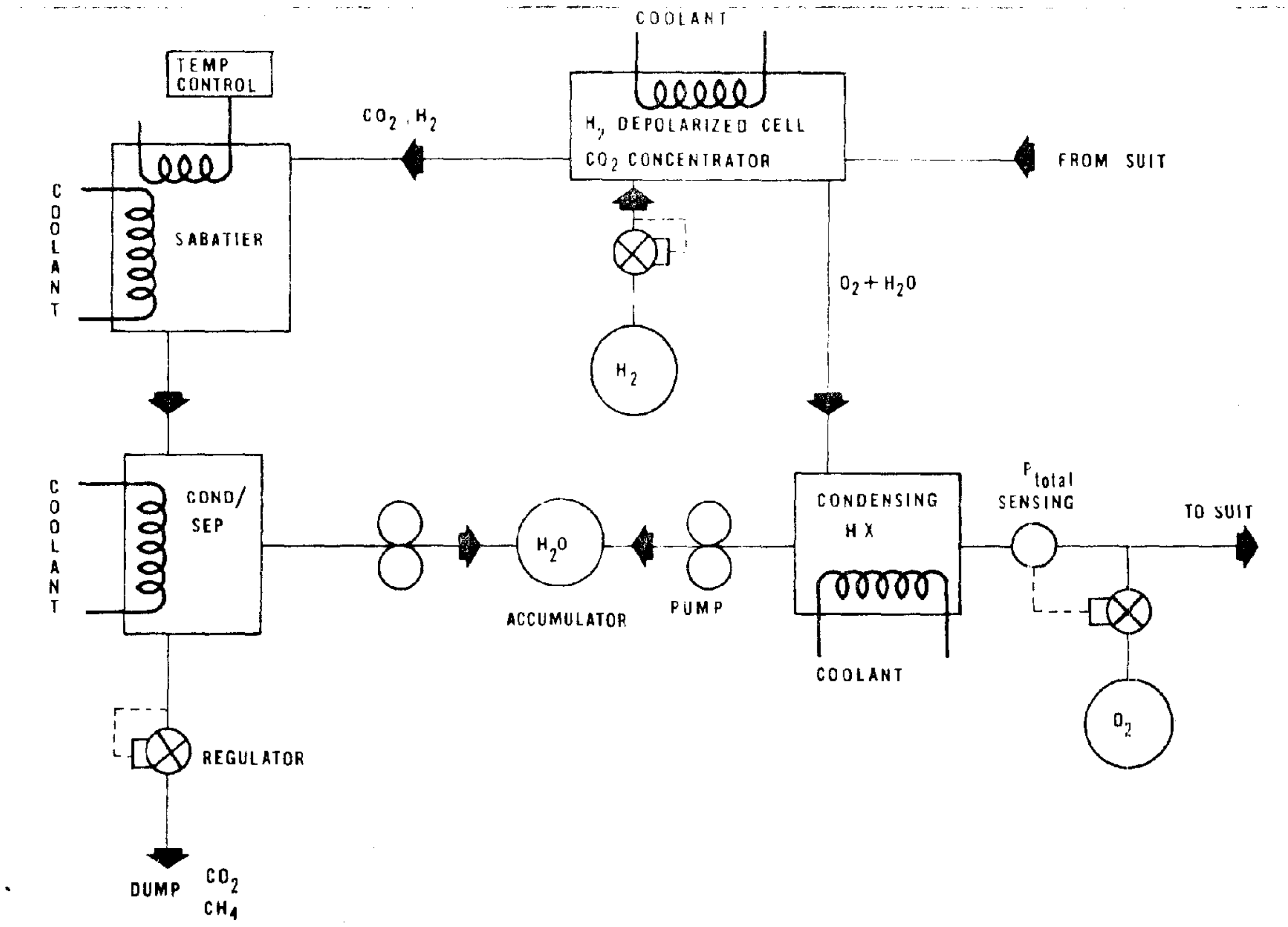
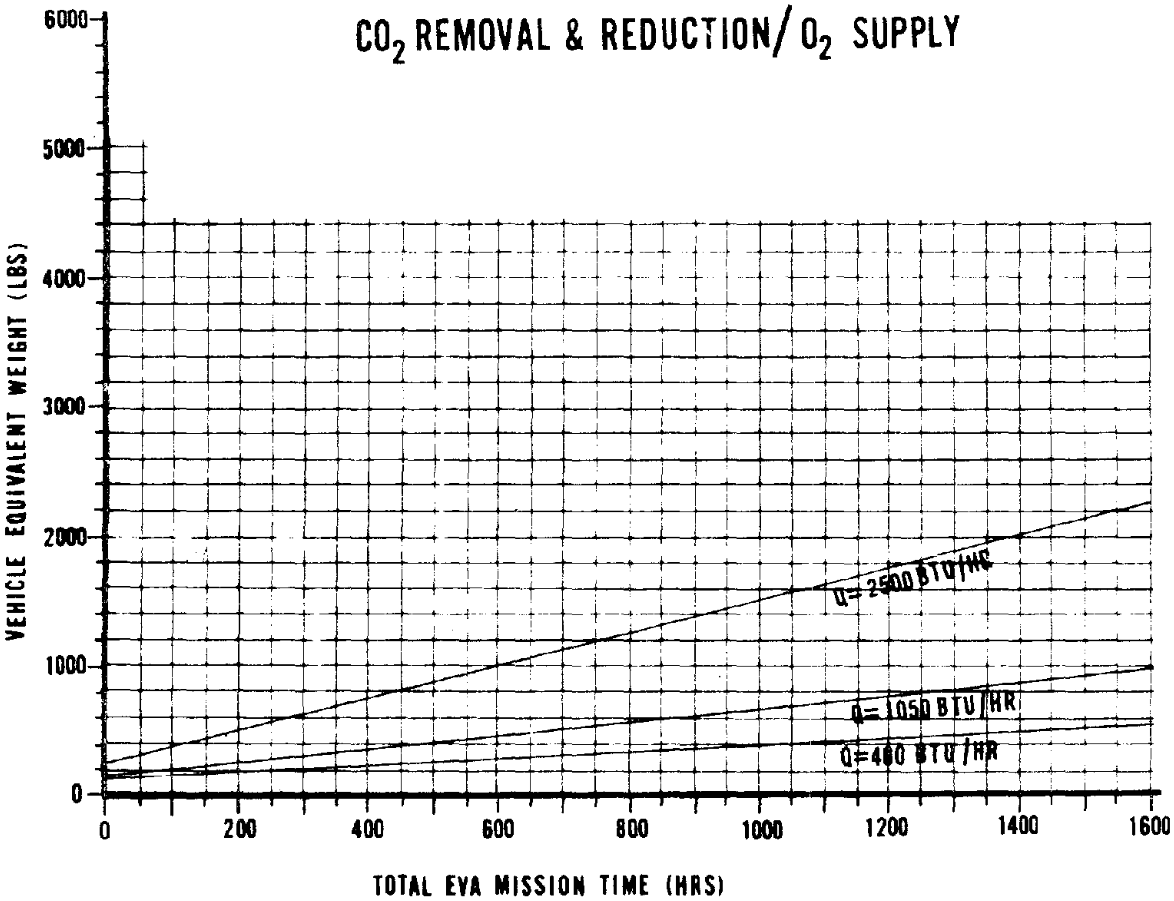
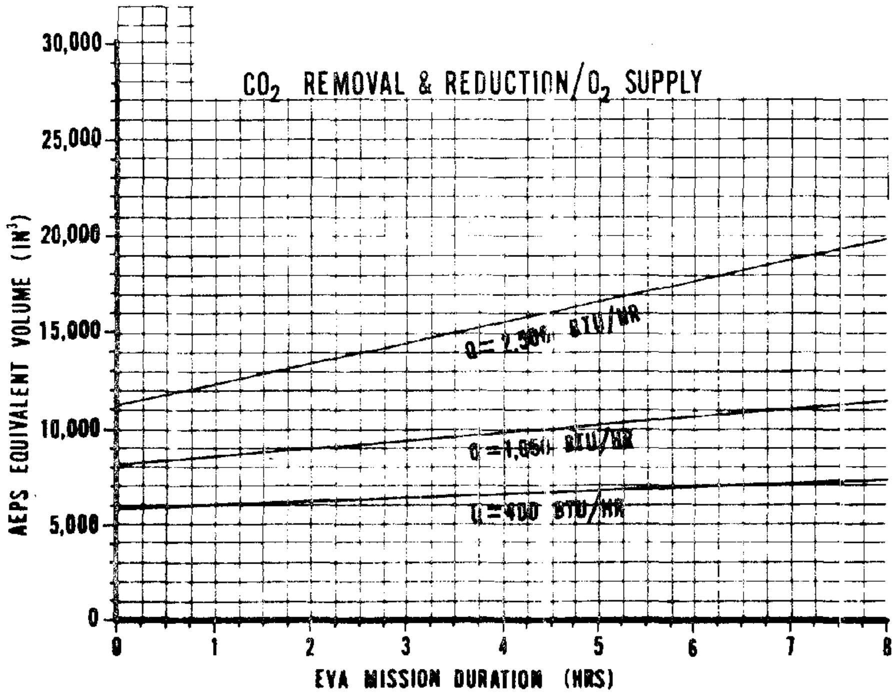
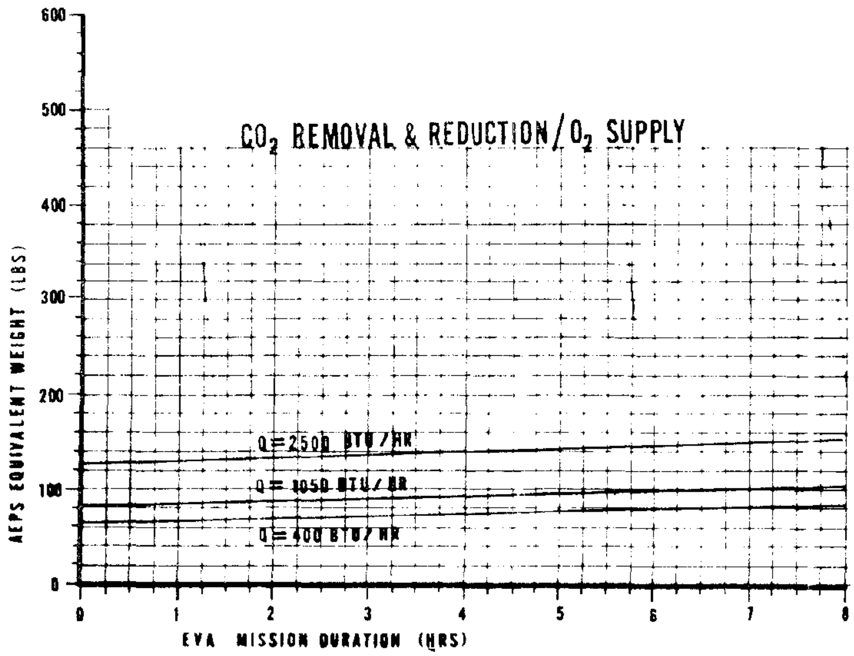


FIGURE 4–31. CO_2 REMOVAL & REDUCTION/O_2 SUPPLY



CO_2 REMOVAL & REDUCTION/ O_2 SUPPLY
6000
5000
4000
3000
2000
1000
0
VEHICLE EQUIVALENT WEIGHT (LBS)
Q= 2500 BTU/HR
Q= 1050 BTU/HR
Q= 400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)


CO_2 REMOVAL & REDUCTION/O_2 SUPPLY
AEPS EQUIVALENT VOLUME (IN^3)
30,000
25,000
20,000
15,000
10,000
5,000
0
Q=2,500 BTU/HR
Q=1,050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)


CO_2 REMOVAL & REDUCTION/O_2 SUPPLY
AEPS EQUIVALENT WEIGHT (LBS)
600
500
400
300
200
100
0
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)

CONCEPT 14 - CO_2 REMOVAL & STORAGE/O_2 SUPPLY

This concept considers CO_2 removal and concentration utilizing a H_2 depolarized cell. The concentrated CO_2 is stored for eventual reduction in the vehicle and the hydrogen, which is removed in the platinum separator, is recirculated to the H_2 depolarized cell. Oxygen is provided from a high pressure gas supply.

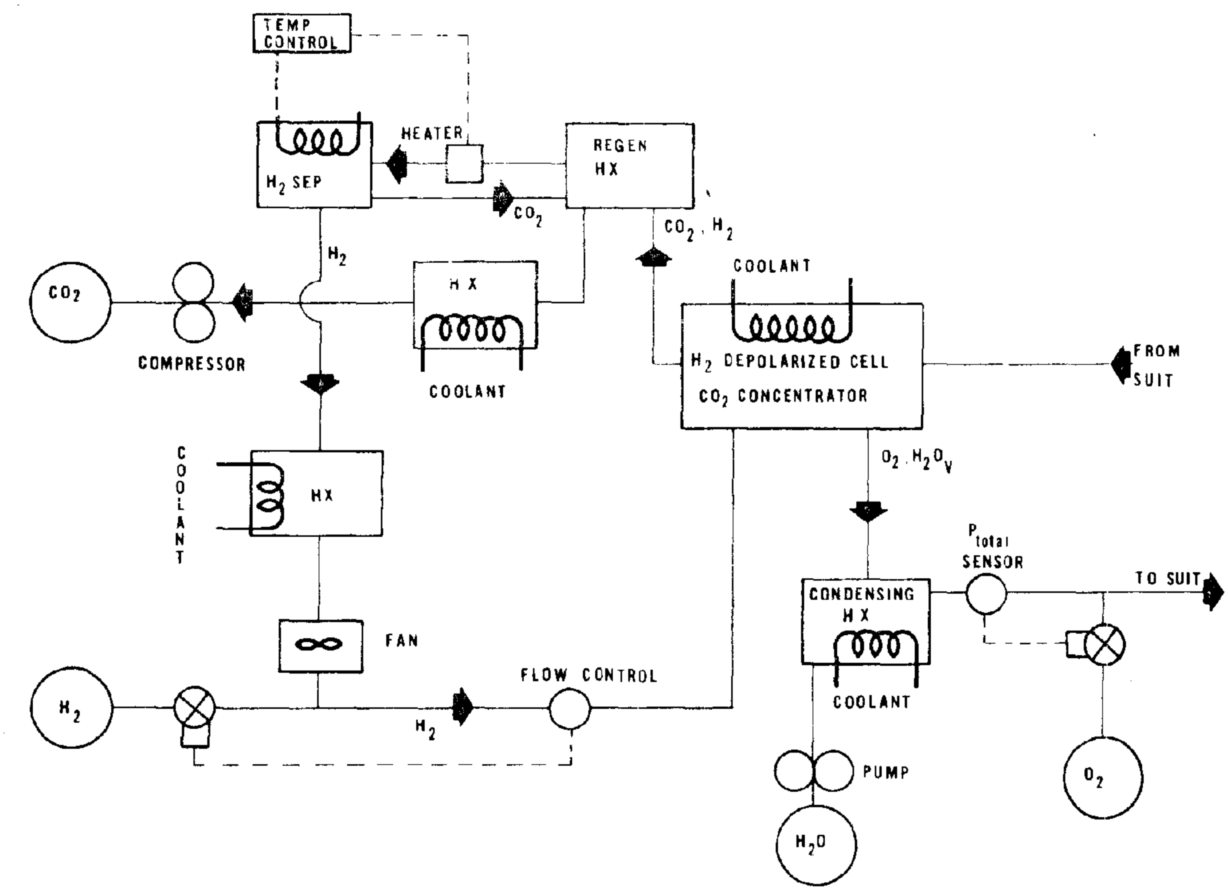
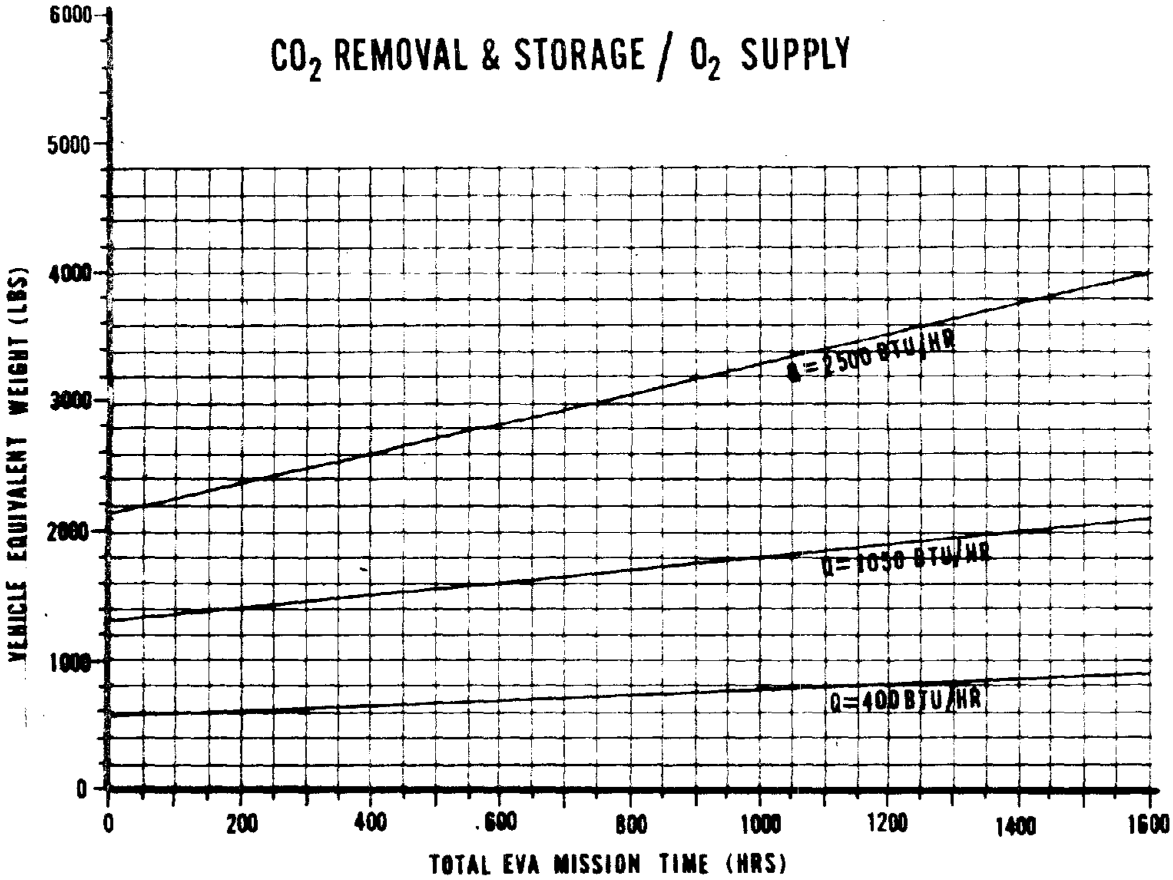
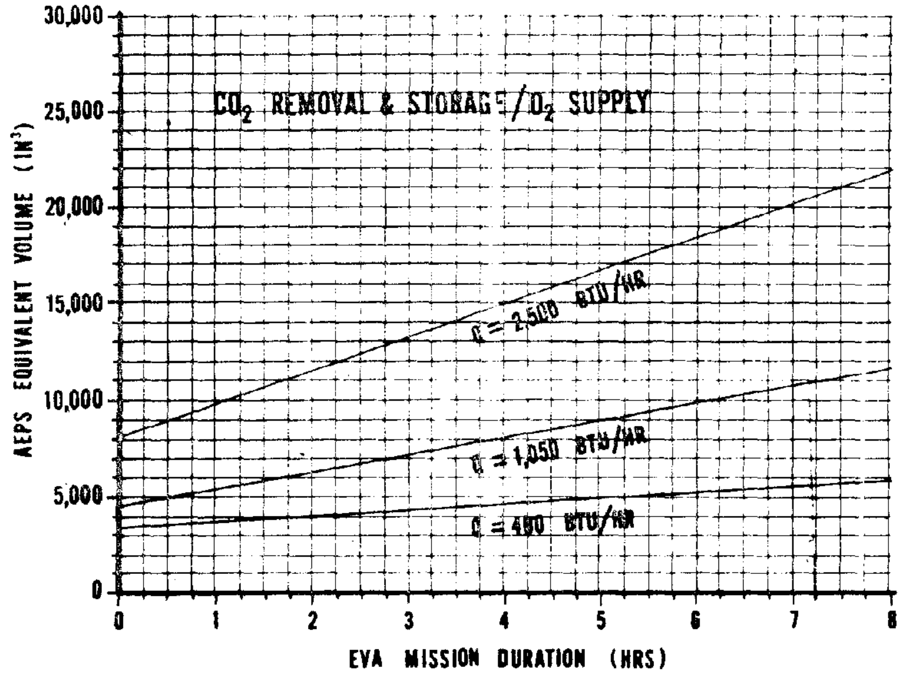


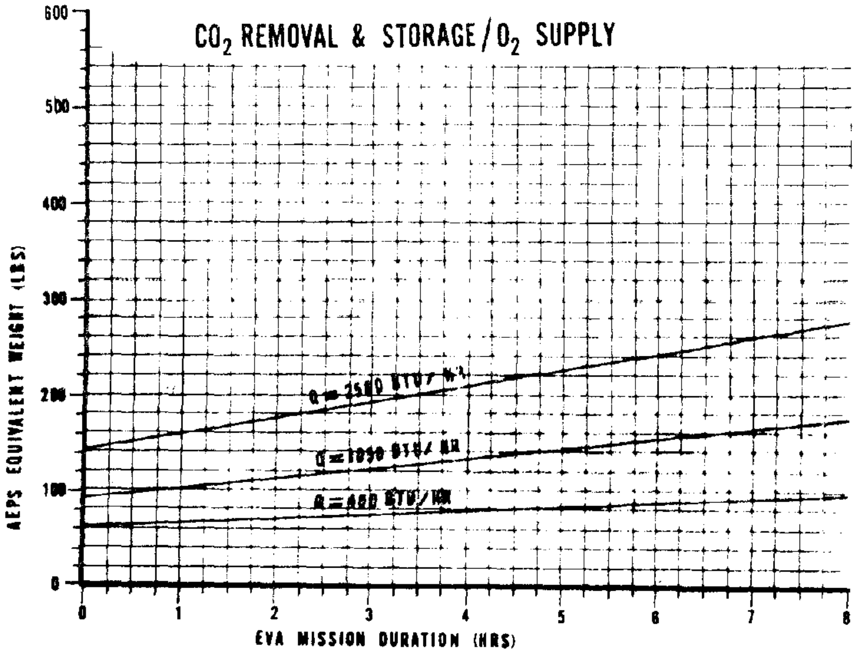
FIGURE 4–32. CO_2 REMOVAL & STORAGE/O_2 SUPPLY



CO_2 REMOVAL & STORAGE / O_2 SUPPLY
6000
5000
4000
3000
2000
1000
0
VEHICLE EQUIVALENT WEIGHT (LBS)
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)



CO_2 REMOVAL & STORAGE/O_2 SUPPLY
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
AEPS EQUIVALENT VOLUME (IN^3)
EVA MISSION DURATION (HRS)



CO_2 REMOVAL & STORAGE/O_2 SUPPLY
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)

CONCEPTS 15 & 16 - CO_2 REDUCTION/O_2 GENERATION

Both of these concepts can be integrated with any of the acceptable regenerable CO_2 control concepts to provide a totally regenerable CO_2 control/O_2 supply subsystem. Wick feed or solid polymer water electrolysis provides makeup oxygen to the vent loop and hydrogen to the Sabatier reactor. CO_2 is drawn from an accumulator in the CO_2 removal subsystem and is reduced to CH_4 and H_2O. Methane is dumped overboard while the water is condensed and returned to the electrolysis feed. The thermal/humidity control heat exchanger conditions the vent loop for return to the astronaut and recycles excess water to the electrolysis cells.

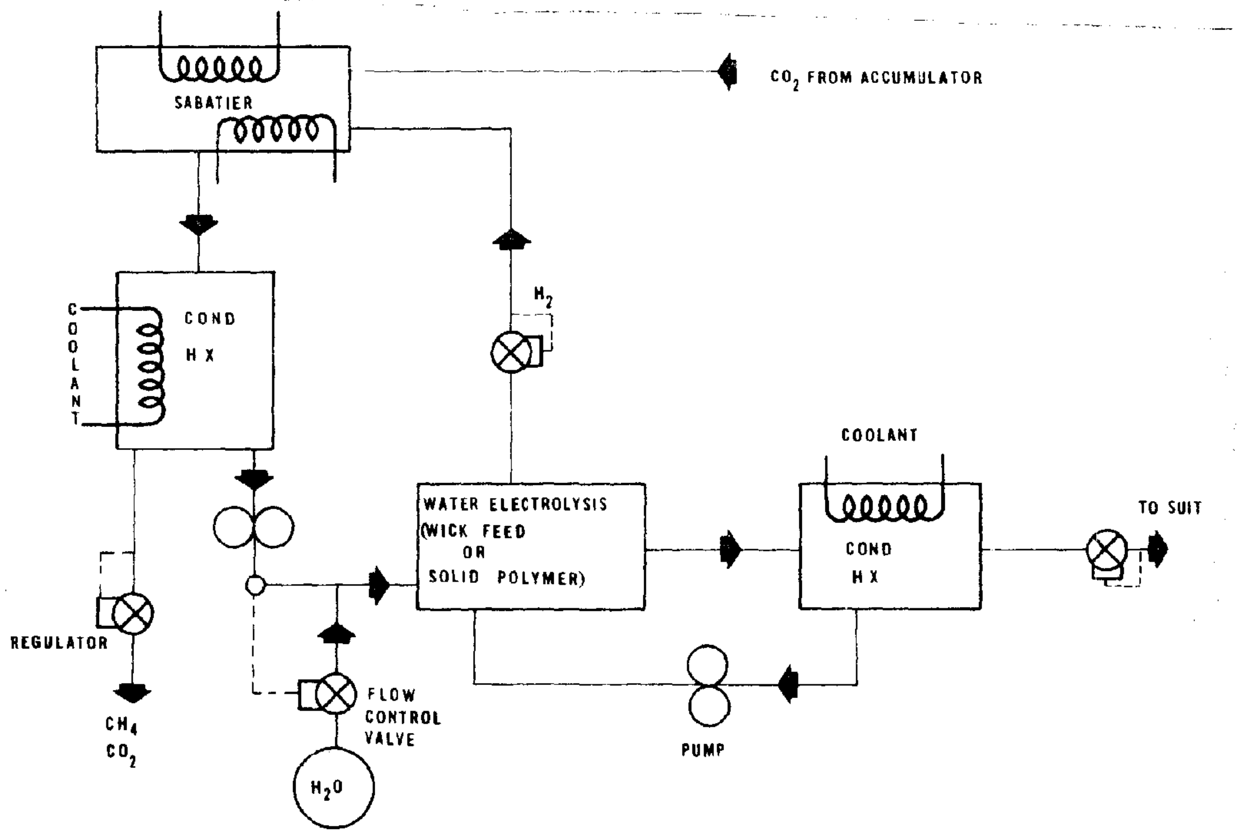
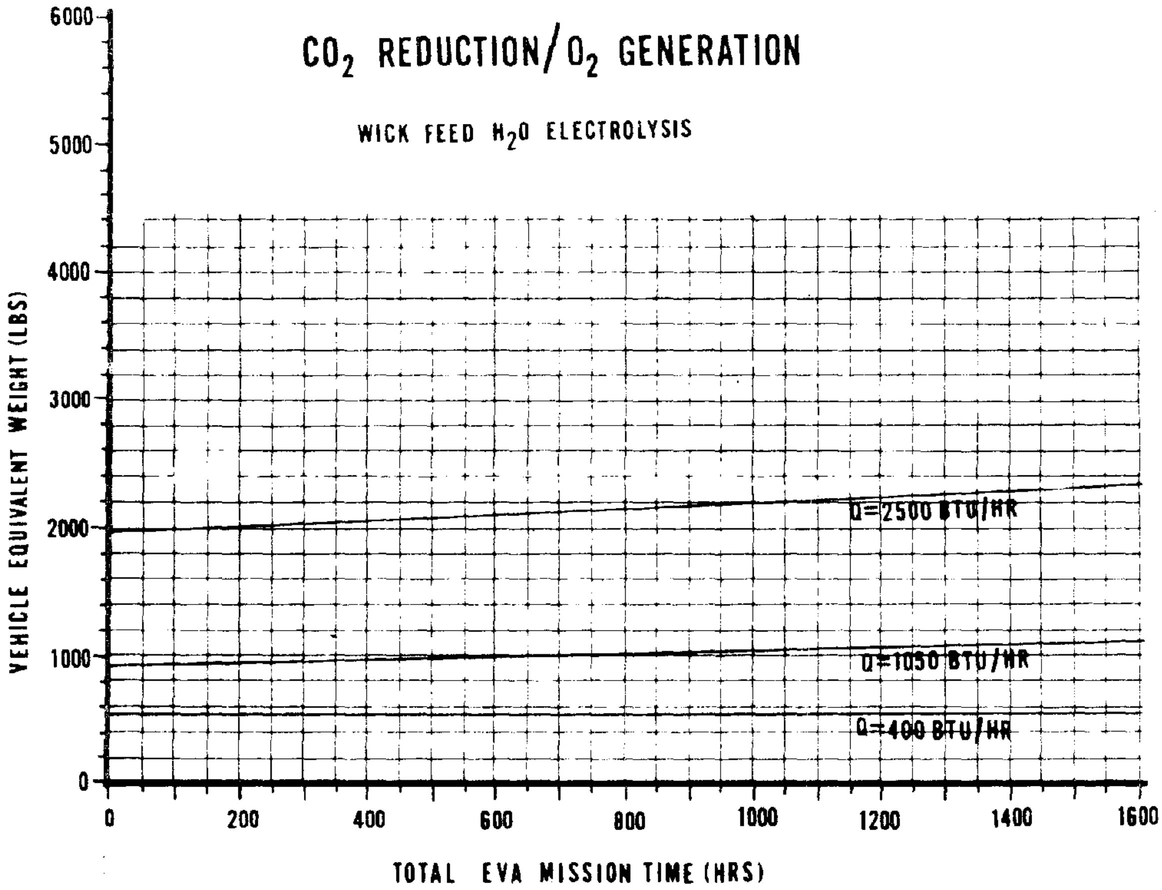
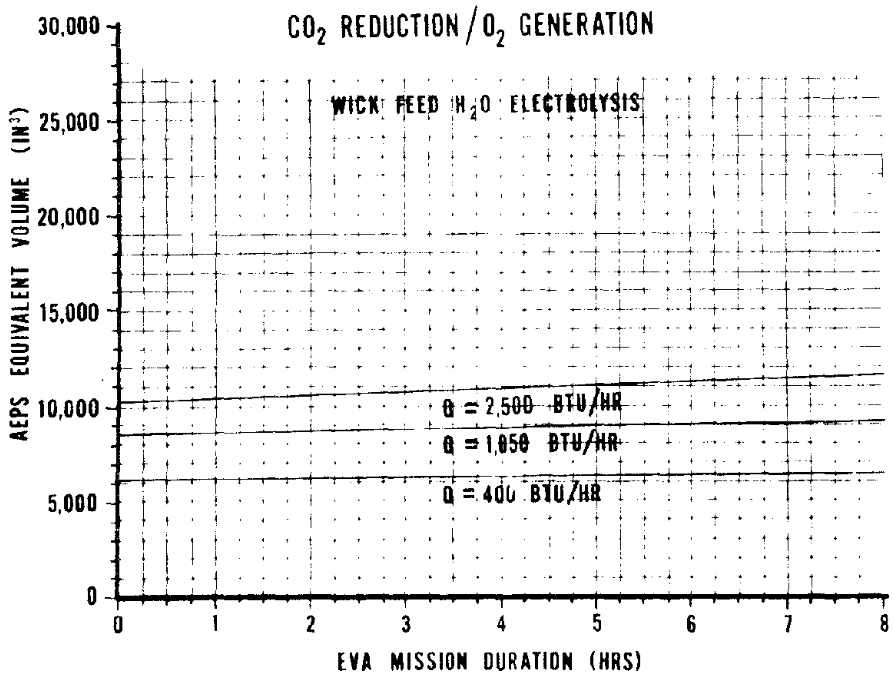


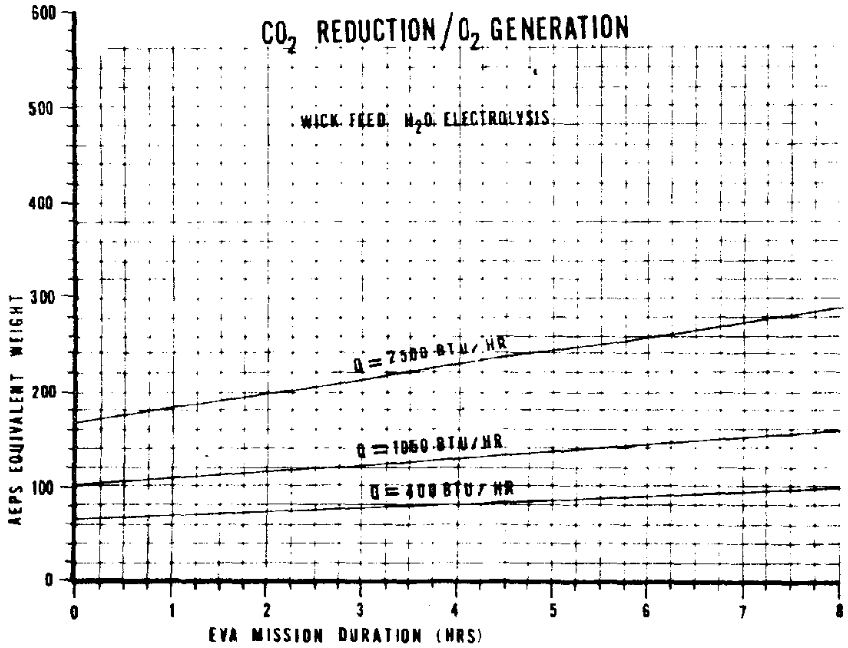
FIGURE 4–33. CO_2 REDUCTION/O_2 GENERATION



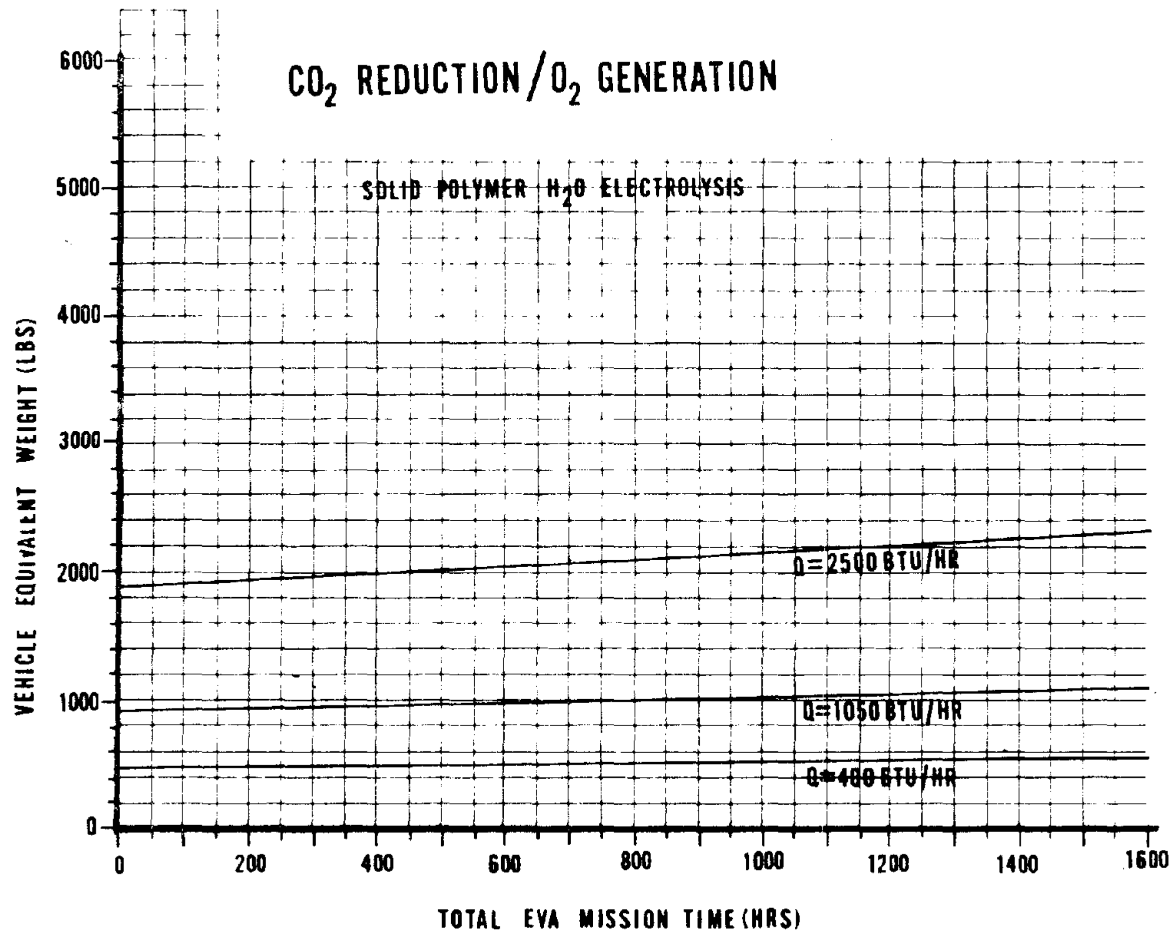
CO_2 REDUCTION/O_2 GENERATION
WICK FEED H_2O ELECTROLYSIS
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
VEHICLE EQUIVALENT WEIGHT (LBS)
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)

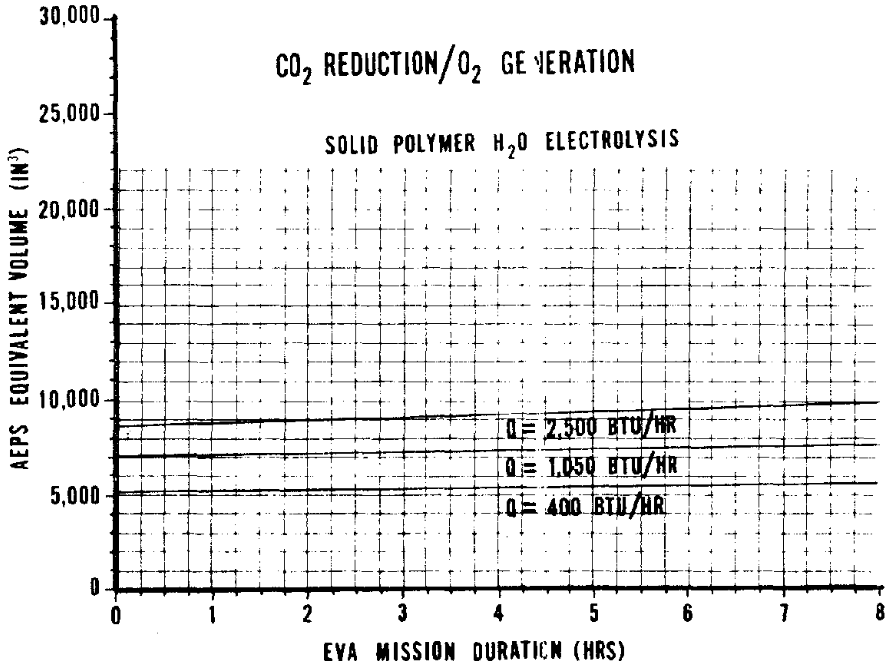


CO_2 REDUCTION / O_2 GENERATION
WICK FEED H_2O ELECTROLYSIS
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
AEPS EQUIVALENT VOLUME (IN^3)
EVA MISSION DURATION (HRS)

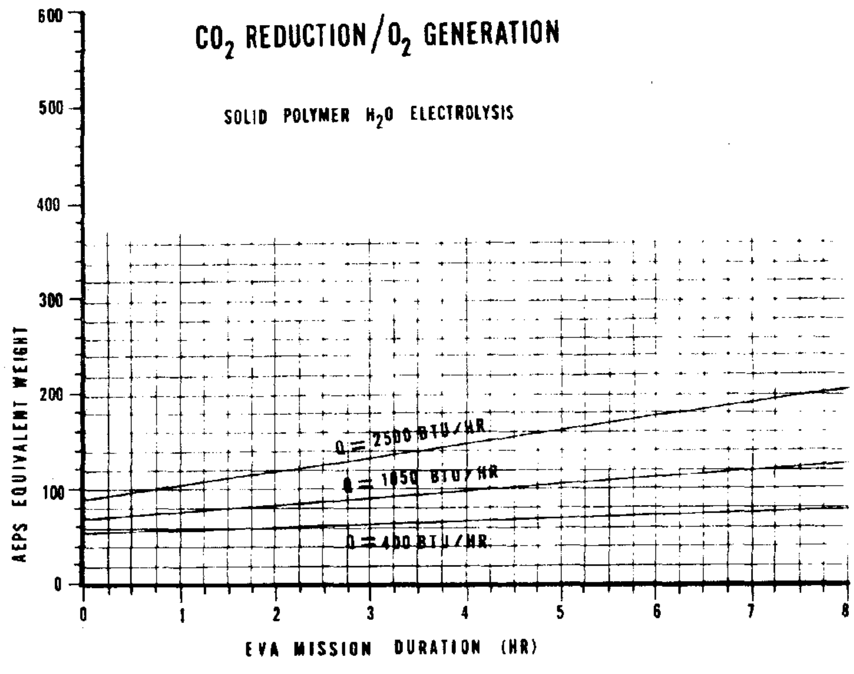


CO_2 REDUCTION / O_2 GENERATION
WICK FEED H_2O ELECTROLYSIS
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR
AEPS EQUIVALENT WEIGHT
EVA MISSION DURATION (HRS)


CO2 REDUCTION/O2 GENERATION
SOLID POLYMER H2O ELECTROLYSIS
Q=2500 BTU/HR
Q=1050 BTU/HR
Q=400 BTU/HR
VEHICLE EQUIVALENT WEIGHT (LBS)
0
1000
2000
3000
4000
5000
6000
0
200
400
600
800
1000
1200
1400
1600
TOTAL EVA MISSION TIME (HRS)



CO_2 REDUCTION/O_2 GENERATION
SOLID POLYMER H_2O ELECTROLYSIS
AEPS EQUIVALENT VOLUME (IN³)
30,000
25,000
20,000
15,000
10,000
5,000
0
Q = 2,500 BTU/HR
Q = 1,050 BTU/HR
Q = 400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HRS)



CO_2 REDUCTION/O_2 GENERATION
SOLID POLYMER H_2O ELECTROLYSIS
AEPS EQUIVALENT WEIGHT
600
500
400
300
200
100
0
Q = 2500 BTU/HR
Q = 1050 BTU/HR
Q = 400 BTU/HR
0
1
2
3
4
5
6
7
8
EVA MISSION DURATION (HR)

4.2 Phase Two Effort

This section consists of the parametric analyses conducted during phase two of the AEPS Study. Section 4.2.1 presents the parametric analyses of the candidate shuttle AEPS subsystem concepts and section 4.2.2 presents the parametric analyses of the candidate emergency system subsystem concepts.

4.2.1 Shuttle AEPS Parametric Analyses

For the shuttle AEPS application, the oxygen supply subsystem parametric analysis evaluated the candidate concepts for an average metabolic load of 1000 BTU/hr and a peak metabolic load of 2500 BTU/hr (for 20 minutes); the thermal/humidity control subsystem parametric analysis evaluated the candidate concepts for an average thermal load of 1300 BTU/hr and a peak thermal load of 3240 BTU/hr with an AEPS power penalty of 100 watt-hrs/lb; the CO_2 control/O_2 supply subsystem parametric analysis evaluated the effect upon the candidate concepts of varying metabolic load (CO_2 production rate) from 400-2500 BTU/hr while maintaining the suit inlet CO_2 partial pressure below 4 mm Hg. Although not shown in the schematics, a nonrechargeable 6000 psi oxygen supply subsystem is included in the parametric data (except for the vehicle umbilical concept).

The shuttle AEPS parametric analyses are contained on the following pages and are based upon extrapolation of in-house and published test data and a projection of both state-of-the-art and design/development improvements achievable by the late 1970's. Note, however, that no parametric data are presented for the thermal/humidity control and CO_2 control/O_2 supply subsystem concepts utilizing a vehicle umbilical.

4.2.1.1 O_2 SUPPLY

CONCEPT 1 - 900 PSI GASEOUS OXYGEN STORAGE

This oxygen supply concept (figure 4-34) utilizes the shuttle vehicle 900 psi minimum storage to repressurize the AEPS after each mission. The basic AEPS oxygen subsystem is fixed within its structure and is charged through the fill fitting.

CONCEPT 2 - 6000 PSI GASEOUS OXYGEN STORAGE

To take advantage of the low AEPS volume afforded by high pressure gaseous oxygen, this concept (figure 4-34) considers shuttle storage of precharged oxygen supply systems. Each system contains a charged 6000 psi oxygen bottle, pressure regulator, pressure gage, fill fitting, shut off valve and low pressure disconnect. The system is serviced and charged on earth between vehicle missions. After each AEPS EVA, the expended or partially expended oxygen storage subsystem is removed and replaced with a fresh unit from storage.

This system minimizes crewtime during AEPS recharge and eliminates the requirement for high pressure connections within the shuttle vehicle.

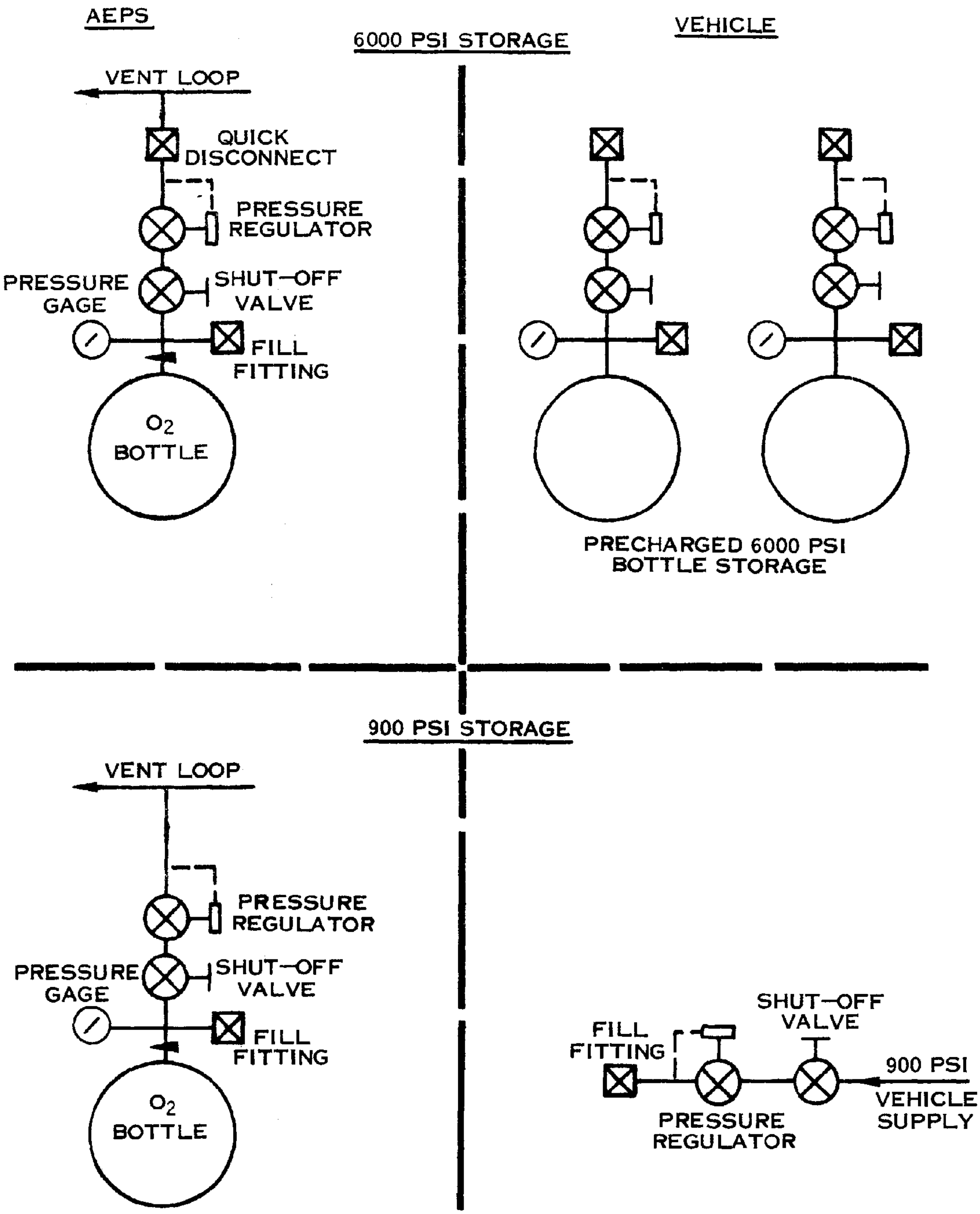


FIGURE 4-34. GASEOUS O_2 SUPPLY

CONCEPT 3 - CHLORATE ($NaClO_3$) CANDLE OXYGEN SUPPLY

In this oxygen supply concept pictured in figure 4-35, electrically ignited chlorate candles are utilized to charge a pressure vessel which then supplies AEPS requirements thru the system pressure control valve. Each candle is sized to provide oxygen at the maximum metabolic rate - the pressure vessel acting as an accumulator for overproduction during periods of below maximum metabolic activity. A filter is used to ensure delivery of pure oxygen to the AEPS.

After each mission, expended candles and the filter are replaced.

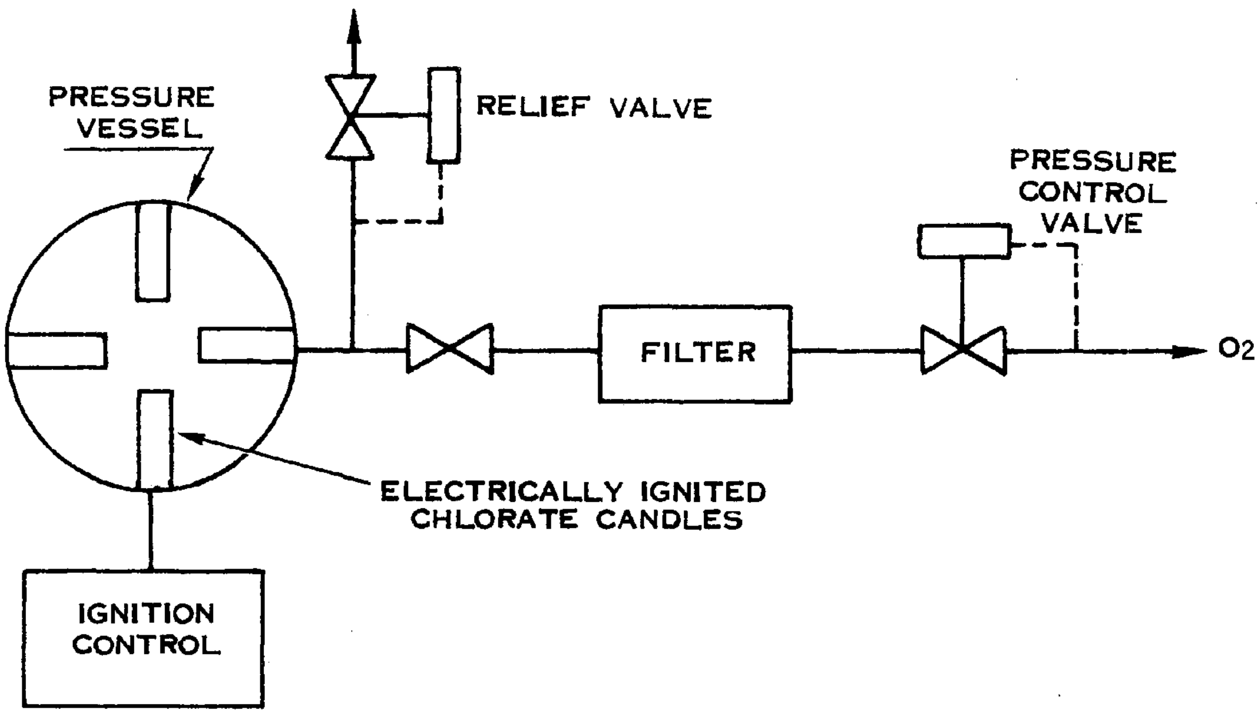
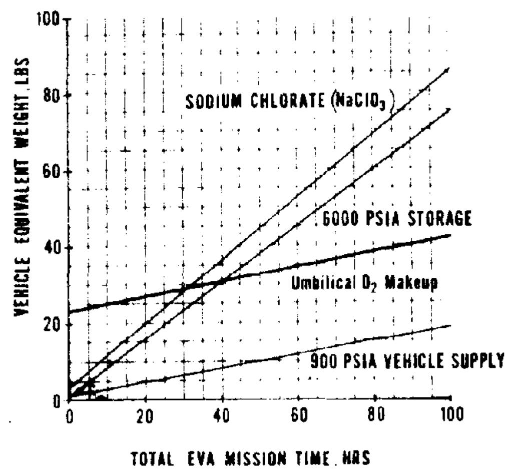


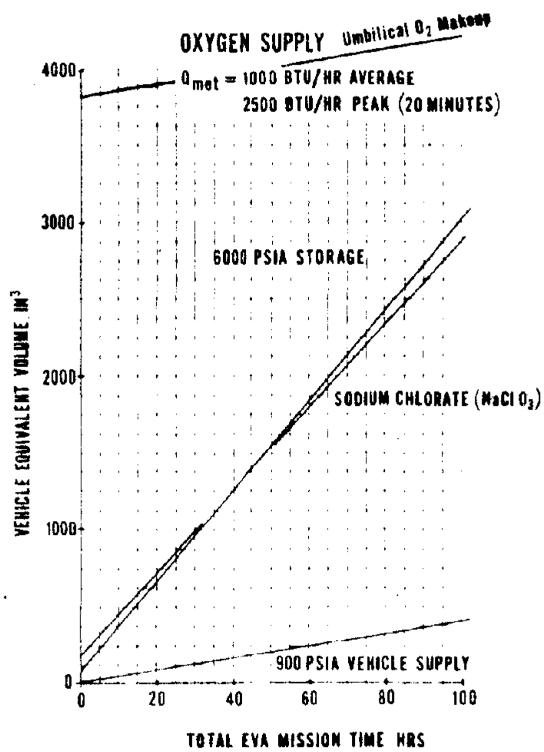
FIGURE 4–35. SODIUM CHLORATE ($NaClO_3$) CANDLE OXYGEN SUPPLY

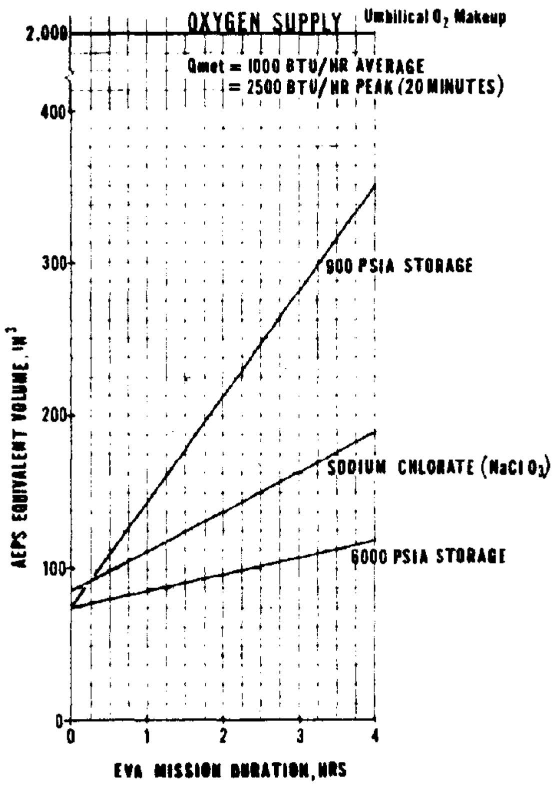
OXYGEN SUPPLY

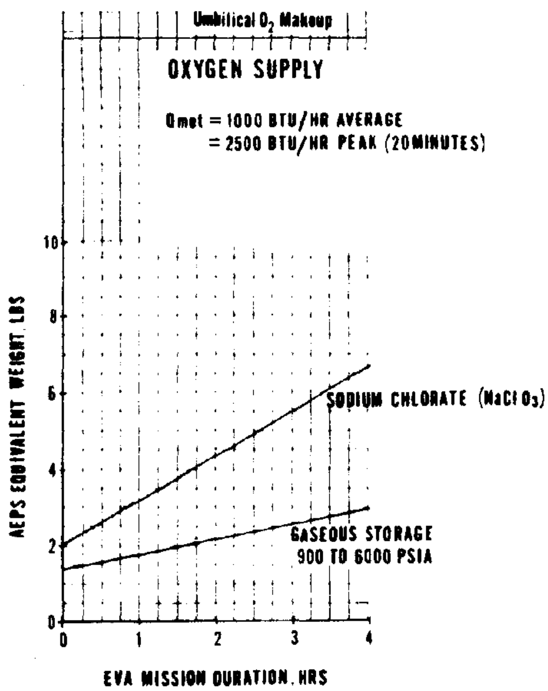
Q_{met} = 1000 BTU/HR AVERAGE
=2500 BTU/HR PEAK (20 MINUTES)



OXYGEN SUPPLY




OXYGEN SUPPLY
Umbilical O_2 Makeup
Qmet = 1000 BTU/HR AVERAGE
= 2500 BTU/HR PEAK (20 MINUTES)
900 PSIA STORAGE
SODIUM CHLORATE ($NaClO_3$)
6000 PSIA STORAGE
AEPS EQUIVALENT VOLUME, IN^3
EVA MISSION DURATION, HRS


Umbilical O_2 Makeup
OXYGEN SUPPLY
Qmet = 1000 BTU/HR AVERAGE
= 2500 BTU/HR PEAK (20MINUTES)
SODIUM CHLORATE ($NaClO_3$)
GASEOUS STORAGE
900 TO 6000 PSIA
AEPS EQUIVALENT WEIGHT, LBS
EVA MISSION DURATION, HRS

O_2 Supply Subsystem Summary

Because of low AEPS volume and weight, the 6000 psi gaseous oxygen storage concept was selected for the remainder of shuttle AEPS subsystem study effort. However, this decision will be reexamined again on the systems level.

4.2.1.2 THERMAL/HUMIDITY CONTROL

CONCEPT 1 - WATER BOILER

The water boiler is an expendable thermal control concept that utilizes the heat of vaporization of water to provide direct cooling of the Liquid Cooling Garment (LCG) loop and vent loop. The wick-fed water boiler also acts as the storage vessel for the expendable water. The expendable water boiling temperature is controlled by a Back Pressure Valve (BPV), which is either a temperature sensing or pressure sensing flow control valve. Crewman comfort is achieved automatically by the Temperature Control Valve (TCV). Separated water is fed into the water boiler, thus providing additional cooling capacity. A relief valve furnishes protection against overpressurization due to storage temperature fluctuations. Recharge is simply accomplished utilizing the fill valve.

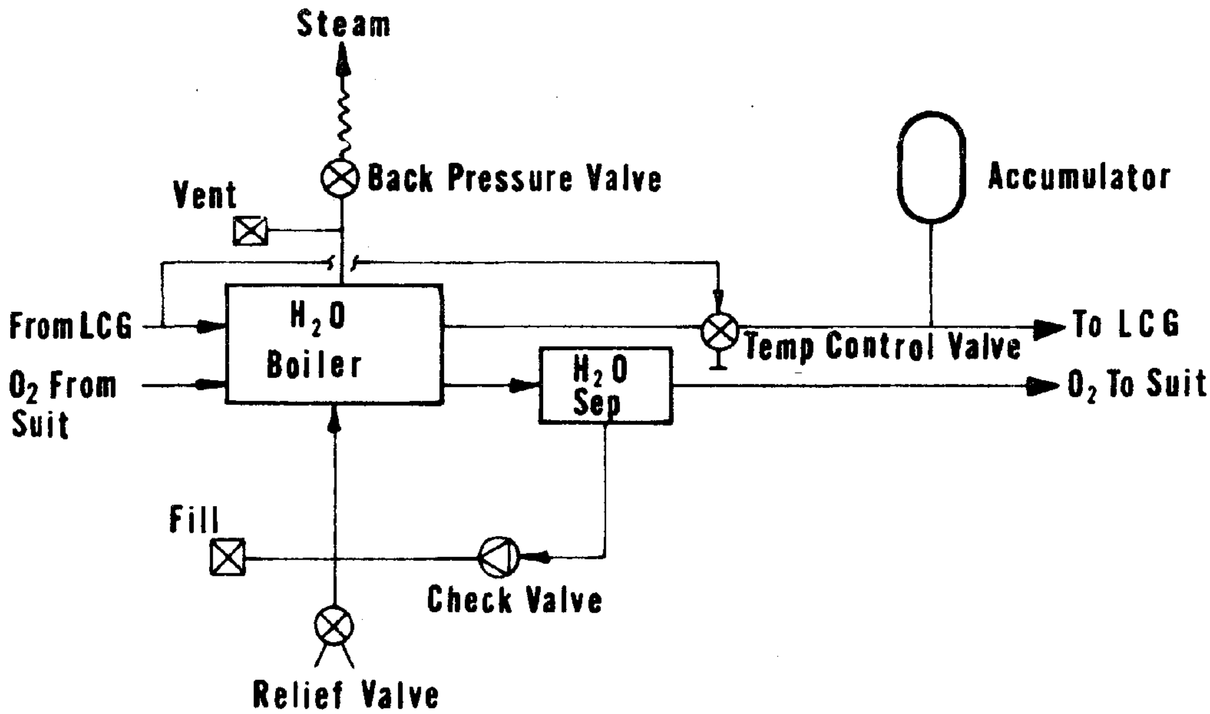
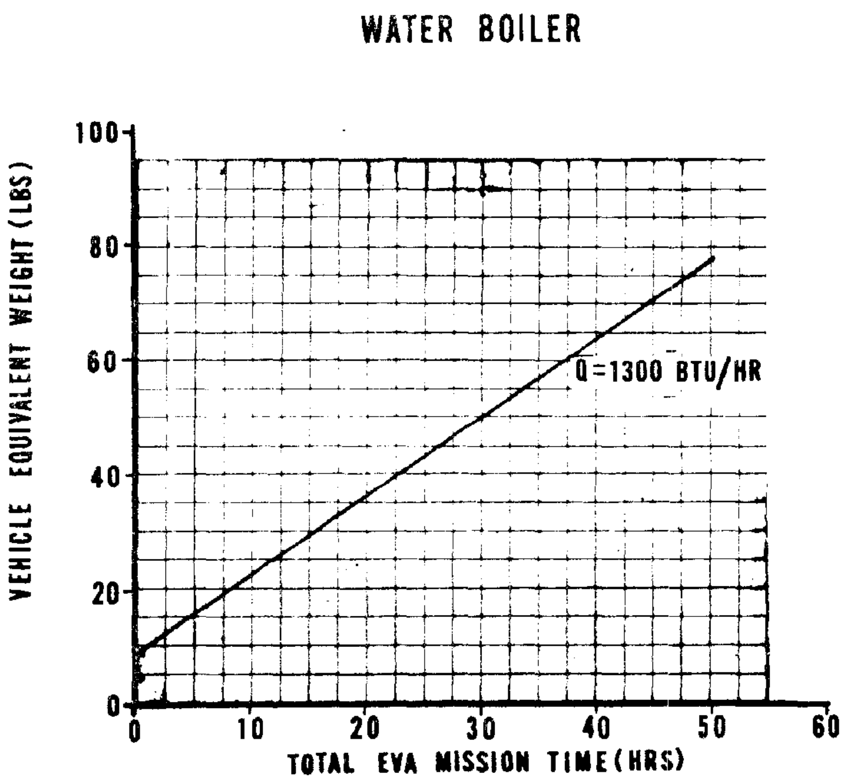
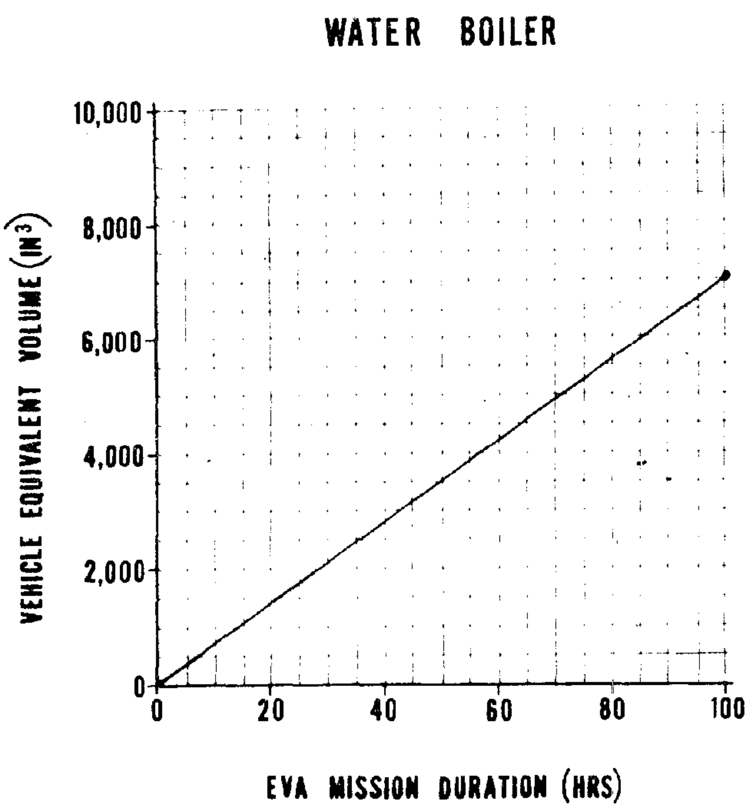
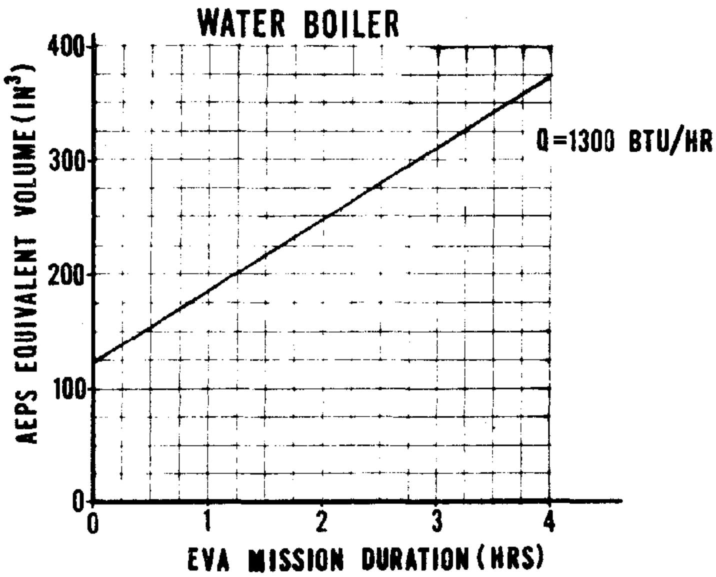
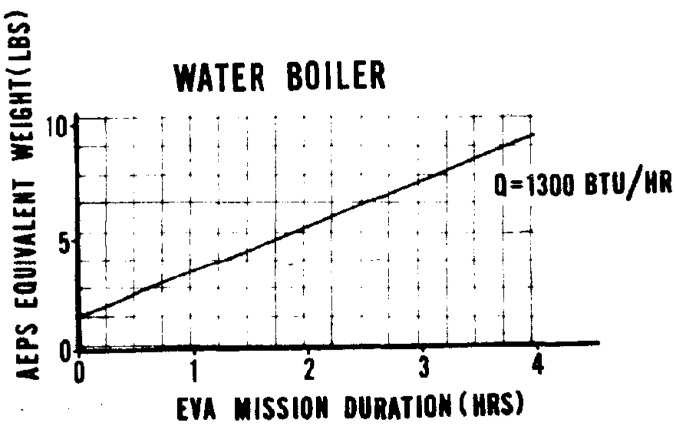


FIGURE 4–36. WATER BOILER


WATER BOILER
100
80
60
40
20
0
0
10
20
30
40
50
60
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)
Q=1300 BTU/HR


WATER BOILER
10,000
8,000
6,000
4,000
2,000
0
0
20
40
60
80
100
VEHICLE EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)


WATER BOILER
AEPS EQUIVALENT VOLUME (IN^3)
400
300
200
100
0
0
1
2
3
4
EVA MISSION DURATION (HRS)
Q=1300 BTU/HR


WATER BOILER
AEPS EQUIVALENT WEIGHT (LBS)
10
5
0
0
1
2
3
4
EVA MISSION DURATION (HRS)
Q=1300 BTU/HR

CONCEPT 2 - WATER SUBLIMATOR

The water sublimator is an expendable thermal control concept that utilizes the heat of sublimation to provide direct cooling of the LCG and vent loops. In order to minimize AEPS expendables, the Apollo EMU sublimator concept was modified to permit utilization of the separated water to provide additional cooling capacity. The sublimator is a porous media heat exchanger wherein the downstream side of the porous media is subjected to hard vacuum and the upstream side is supplied with expendable water. Upon startup, the sudden drop in pressure across the porous media freezes the expendable water within the porous media. The addition of heat from the LCG and vent loops sublimes the ice on the vacuum end of the porous media and thus the thermal load is rejected to space. The sublimator is supplied expendable water from a pressure-fed bladder tank which is pressurized by the vent loop. A flow limiting orifice prevents breakthrough of the sublimator on startup.

A motor driven rotary water separator positively expels separated water from the vent loop downstream of the sublimator to the feed side of the water reservoir. A check valve insures positive separated water expulsion and a gas trap (may not be required) prevents sublimator breakthrough from gas bubbles. Check and relief valves are added for safety and a fill connector and dump valve permits recharge. The TCV provides LCG temperature control. This concept will not work on Mars because of the atmospheric pressure on Mars.

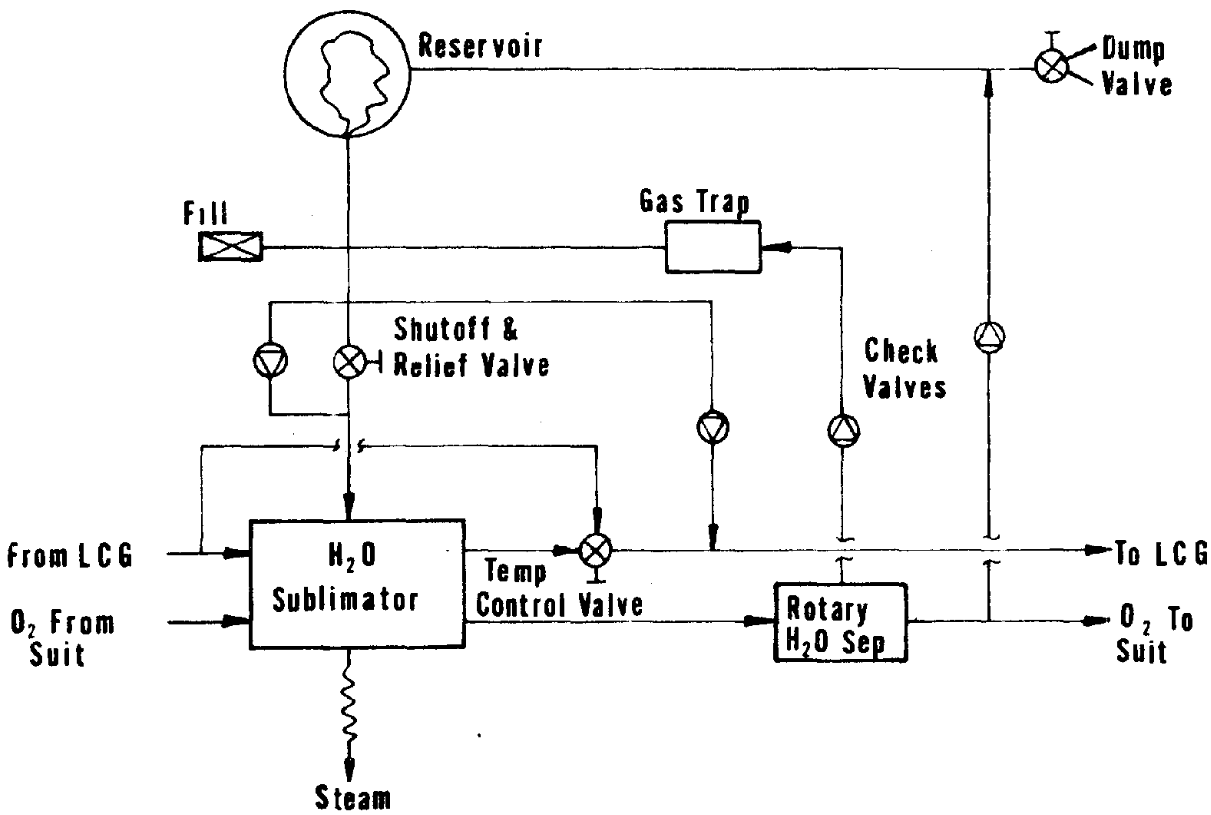
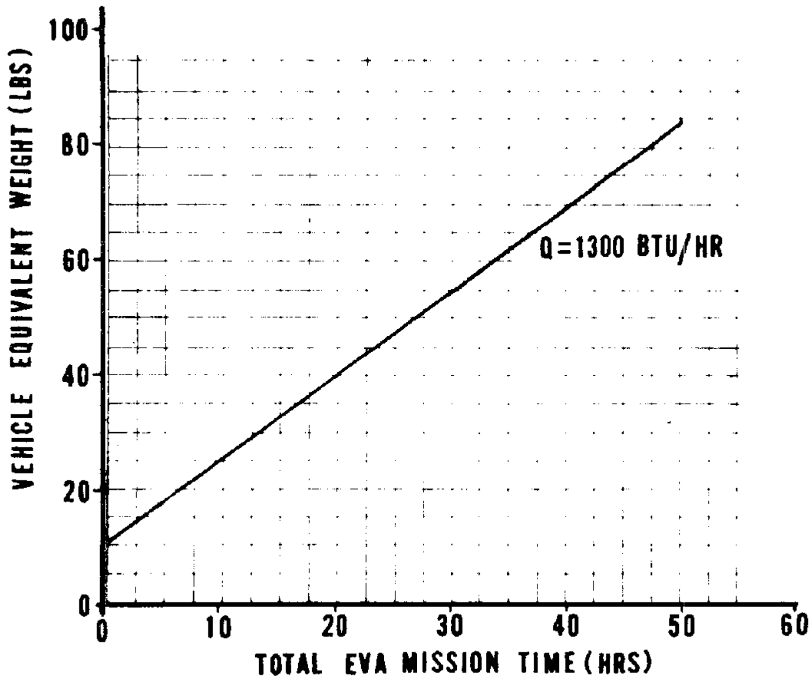
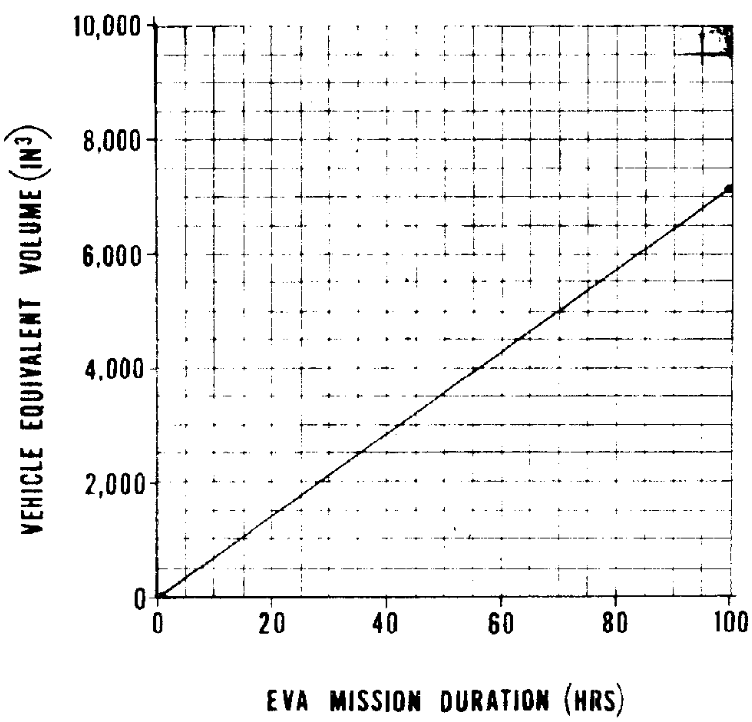


FIGURE 4–37. WATER SUBLIMATOR

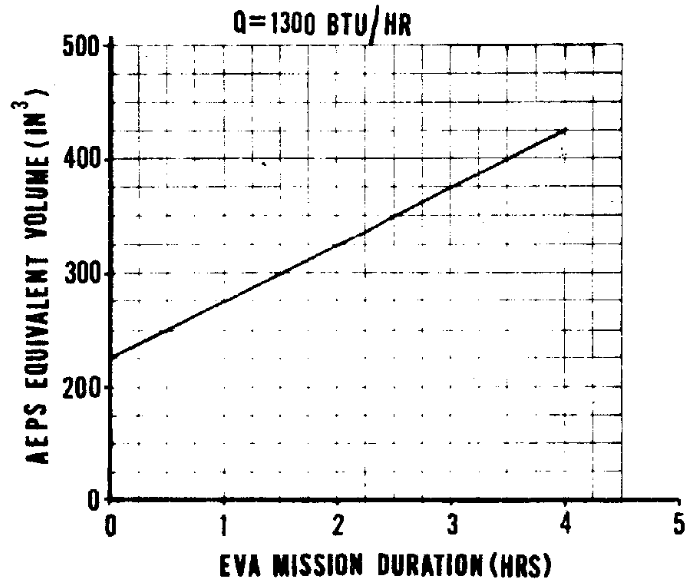
WATER SUBLIMATOR



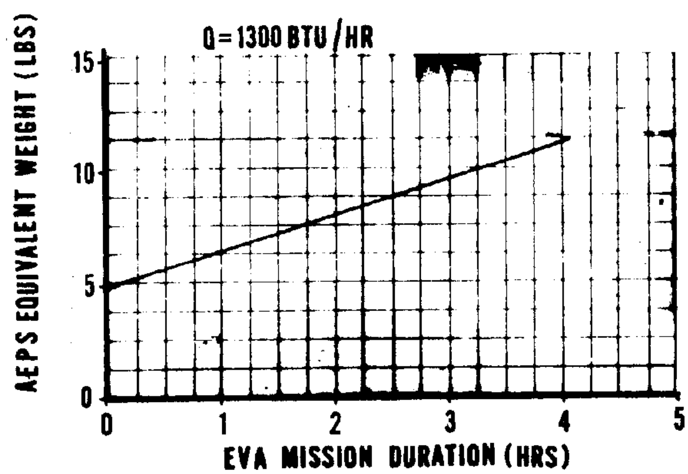
WATER SUBLIMATOR



WATER SUBLIMATOR



WATER SUBLIMATOR



CONCEPT 3 - THERMAL STORAGE (PH_4Cl)

Thermal storage utilizing phosphonium chloride (PH_4Cl) is a self-regenerable thermal control concept. PH_4Cl is a chemical that has a heat of fusion of 324 BTU/lb at 82°F and 48 atmospheres pressure and has an estimated specific gravity of 1.7. It is formed at low temperature from phosphine (PH_3) and hydrogen chloride (HCl). A vapor compression intermediate loop is utilized to raise the desired coolant temperature of 50°F at the O_2/LCG heat exchanger to 82°F at the thermal storage unit. Humidity control is furnished by a water separator and holding tank which removes and stores vent loop condensate. Vehicle penalties associated with this concept are relatively low, since PH_4Cl will resolidify of its own accord at normal cabin temperatures.

Solid PH_4Cl sublimates at pressures below 700 psia at room temperature. As pressure is decreased further, gaseous PH_4Cl dissociates into two gases: (1) Hydrogen chloride and (2) Phosphine (PH_3). PH_3 is highly toxic and therefore, the thermal storage unit has been concepted so as to minimize the probability of any failure resulting in external leakage.

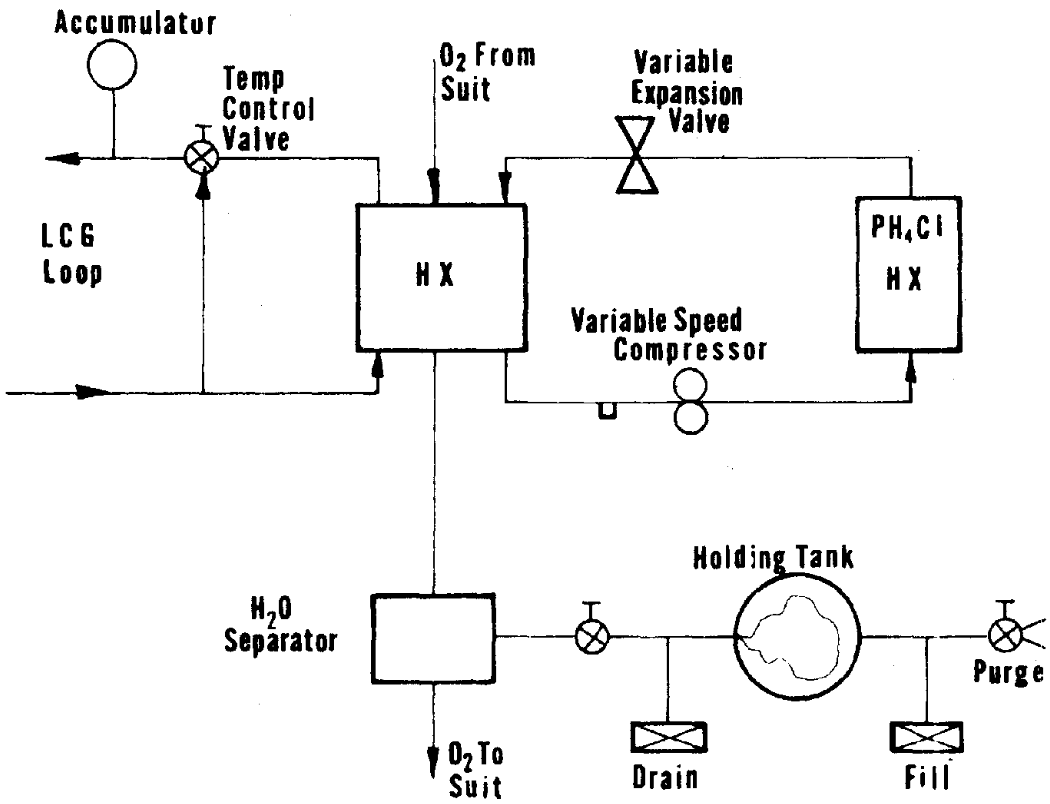
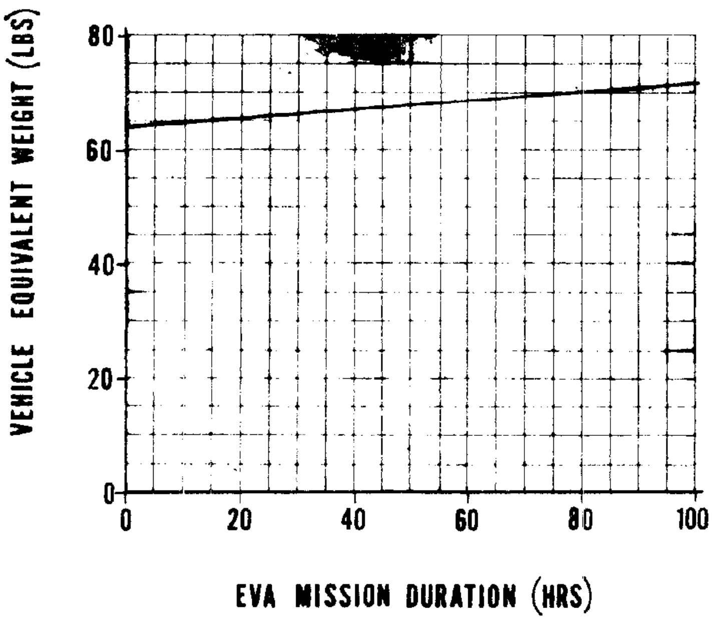


FIGURE 4–38. THERMAL STORAGE – PH_4 Cl

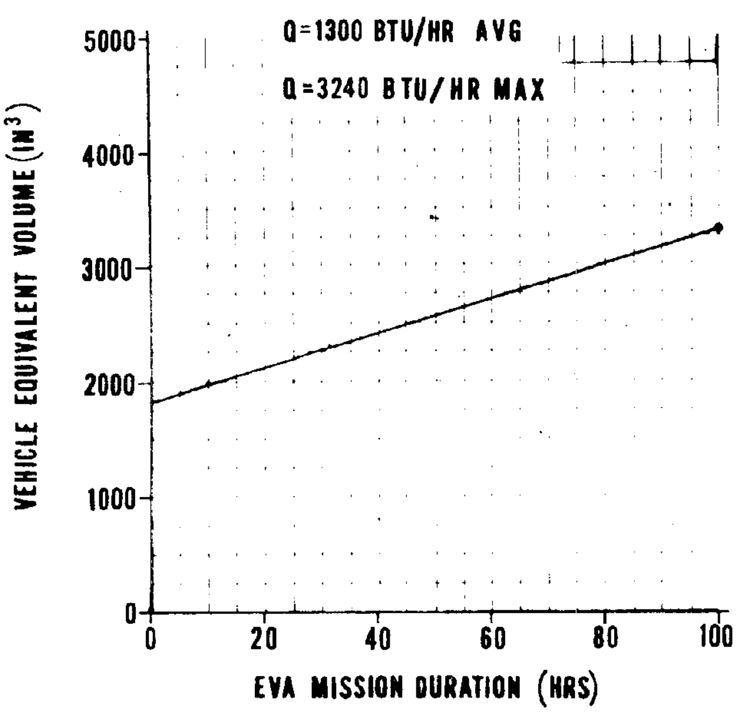
THERMAL STORAGE - PH_4Cl

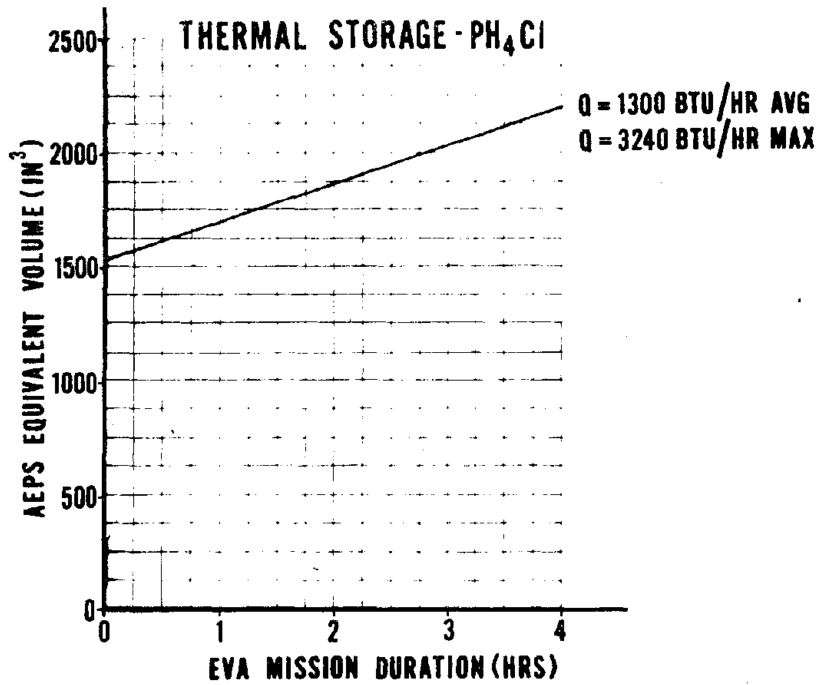
Q=1300 BTU/HR AVG

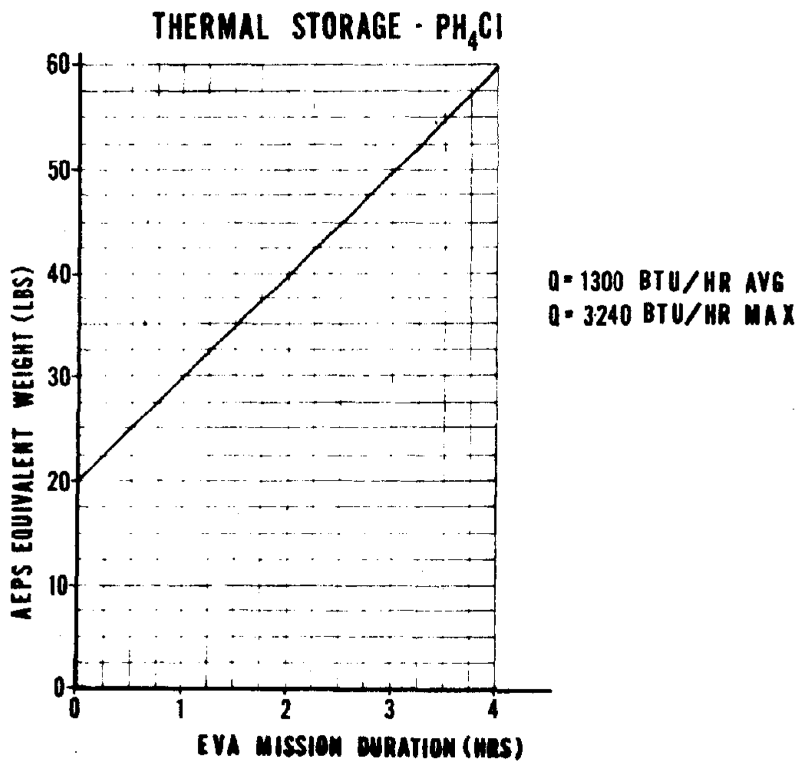
Q=3240 BTU/HR MAX



THERMAL STORAGE-PH_4Cl




THERMAL STORAGE - PH_4Cl
Q = 1300 BTU/HR AVG
Q = 3240 BTU/HR MAX
AEPS EQUIVALENT VOLUME (IN^3)
2500
2000
1500
1000
500
0
0
1
2
3
4
EVA MISSION DURATION (HRS)


THERMAL STORAGE - PH_4Cl
Q = 1300 BTU/HR AVG
Q = 3240 BTU/HR MAX
AEPS EQUIVALENT WEIGHT (LBS)
60
50
40
30
20
10
0
0
1
2
3
4
EVA MISSION DURATION (HRS)

CONCEPT 4 - THERMAL STORAGE (ICE)

Thermal storage is a regenerable thermal control concept that utilizes the heat of fusion and the heat capacity of a material to provide thermal control. Direct cooling of the vent loop and the LCG is achieved in the thermal storage unit utilizing the heat of fusion of ice and superheating the water from 32 to 50°F. Vent loop humidity control is achieved by condensation of the water vapor in the thermal storage unit and separation and removal of the condensate by the water separator and holding tank. The TCV provides automatic LCG temperature control.

Regeneration of the thermal storage unit dictates the necessity for a vehicle refrigeration system. The thermal storage unit may be regenerated either by insertion of precooled ice cartridges or by incorporation of cooling coils within the thermal storage unit. If a cooling coil approach is employed, it may be necessary to add an intermediate coolant loop to prevent freeze-up of the LCG and/or the vent loop. This would slightly increase weight and volume.

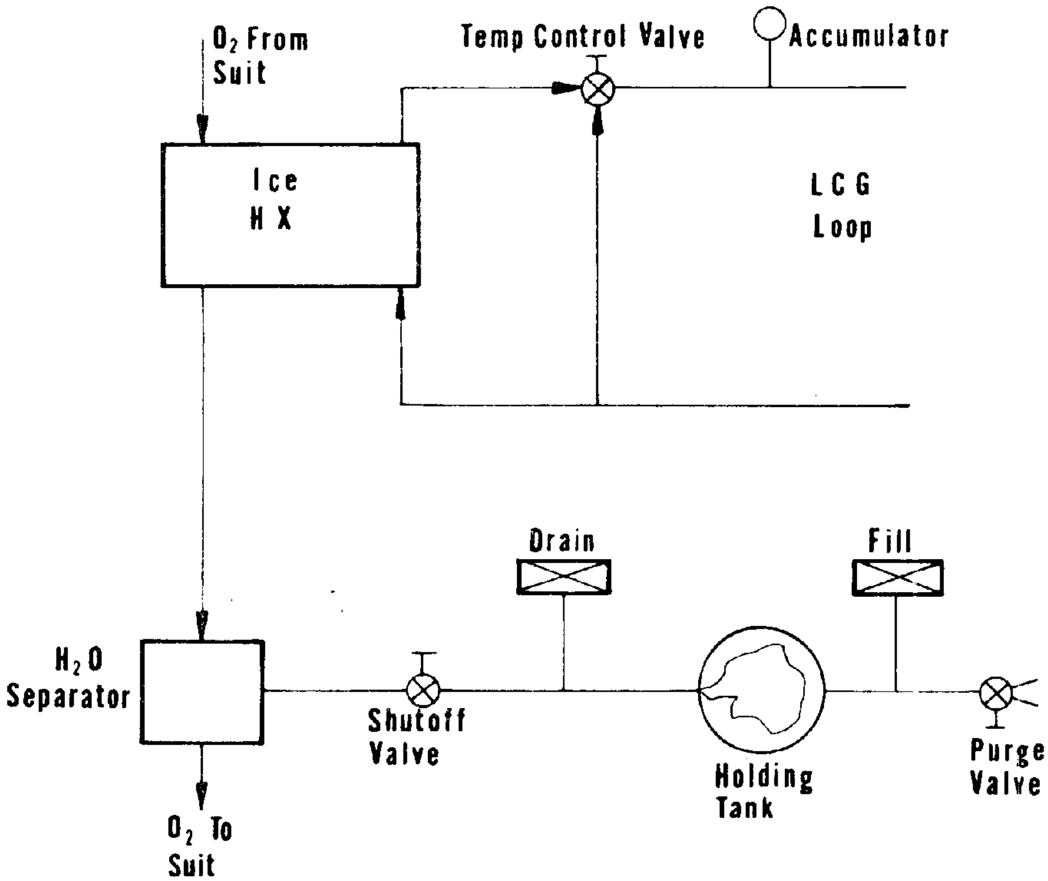
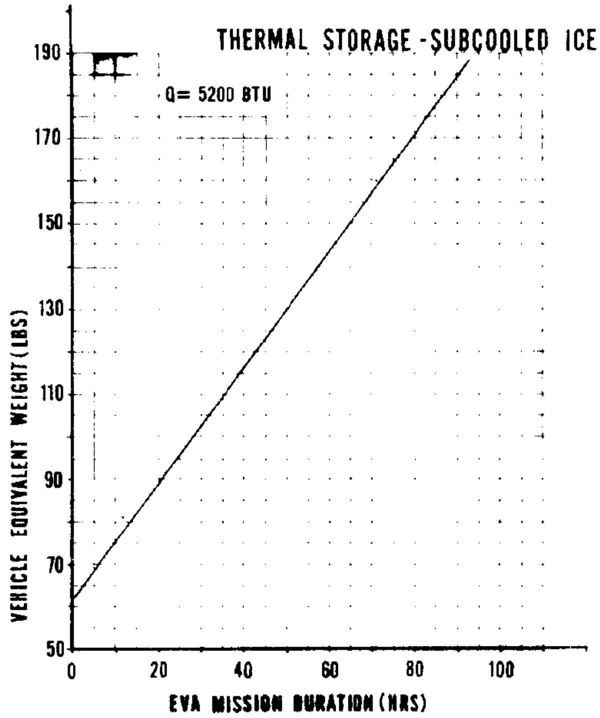
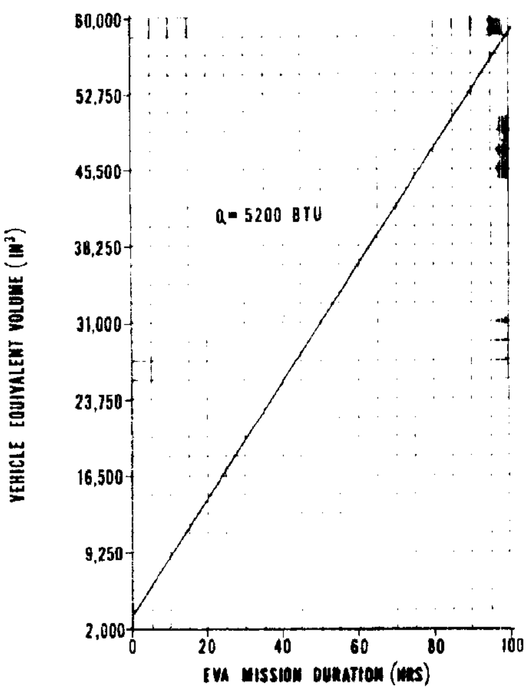


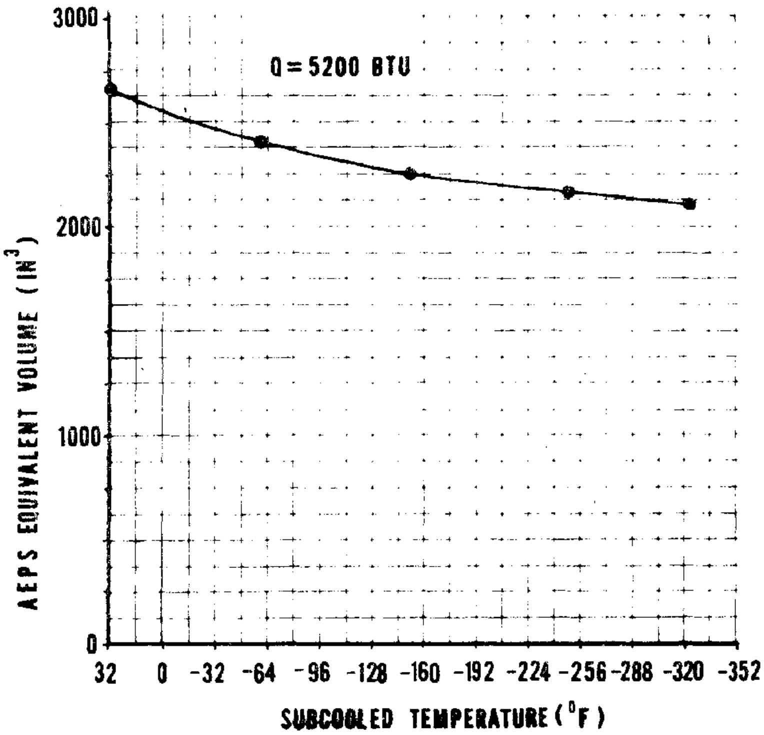
FIGURE 4–39. THERMAL STORAGE – ICE



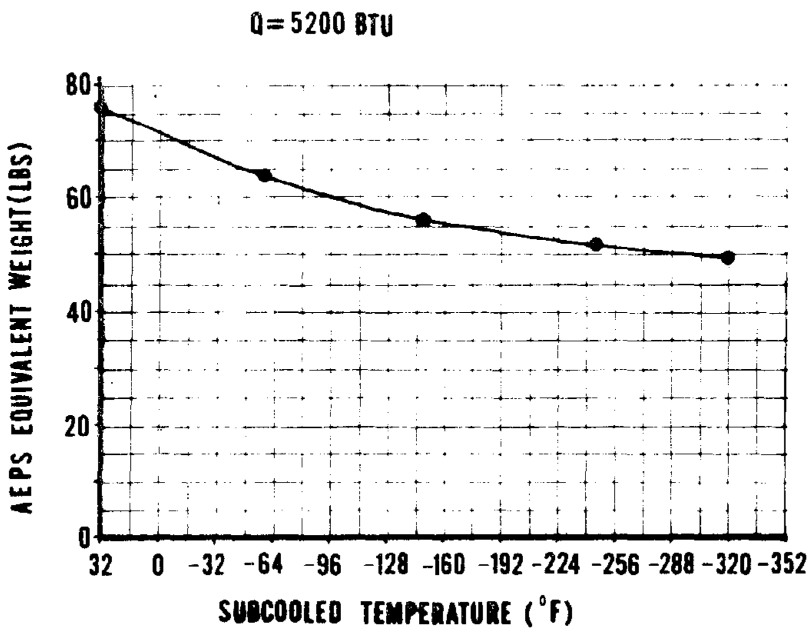
THERMAL STORAGE - SUBCOOLED ICE



THERMAL STORAGE - SUBCOOLED ICE



THERMAL STORAGE - SUBCOOLED ICE



CONCEPT 5 - EXPENDABLE/RADIATION

This hybrid concept consists of a radiator/vapor compression cycle and a water boiler connected in parallel through an automatic LCG temperature control valve. The temperature control valve selects what percentage of the heat load from the LCG is shared by each subsystem. The radiator/vapor compression subsystem is sized to handle the average LCG heat load plus the heat load from the vent system while the H_2O boiler handles peak heat loads. This minimizes radiator size, compressor size, and power consumption as well as water expended in the boiler.

Humidity control is provided by the vapor compression cycle evaporator and the water separator which feeds the separated water to the water boiler to provide additional cooling capacity. For low or no load conditions, a variable speed compressor and variable expansion valve are required to prevent over-cooling at the evaporator. As in the case of the direct radiation concept, normal maintenance is required to sustain radiator performance.

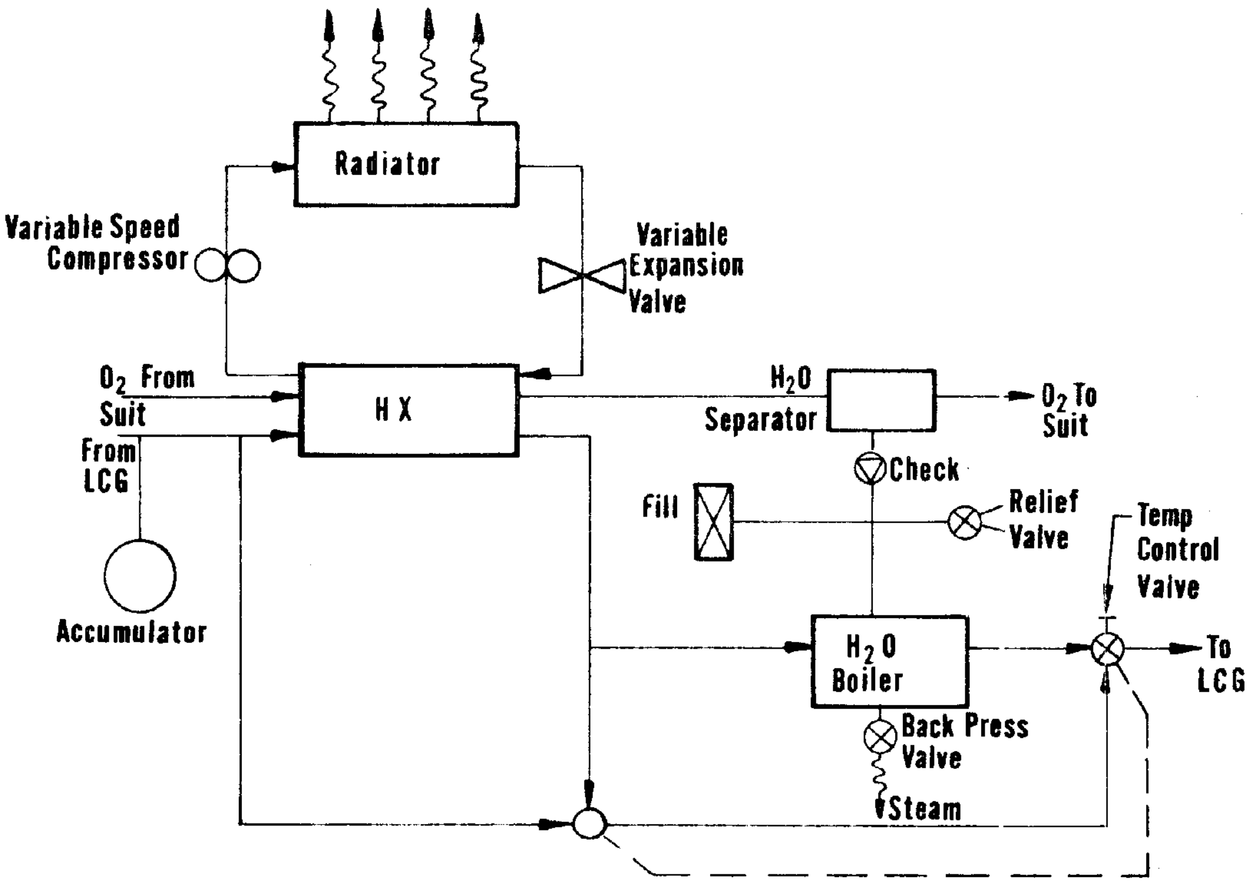
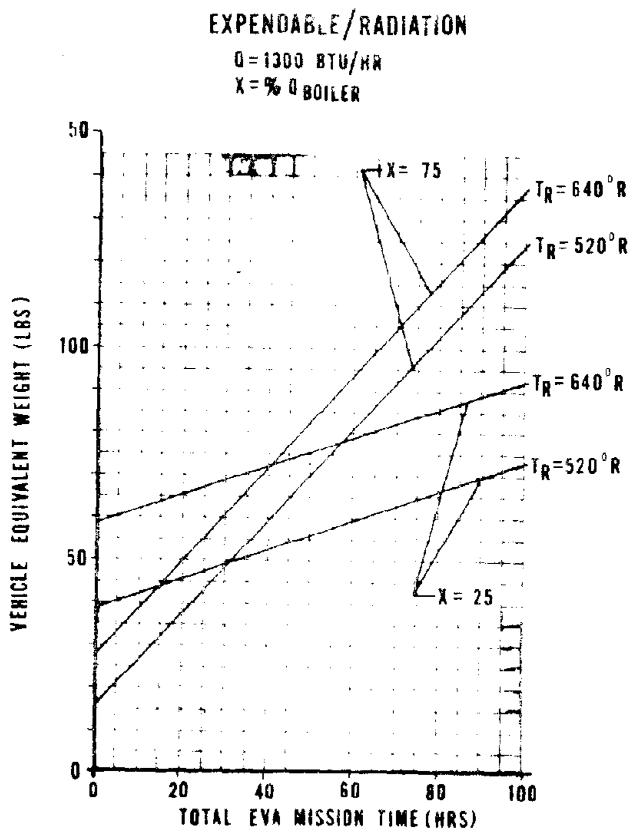
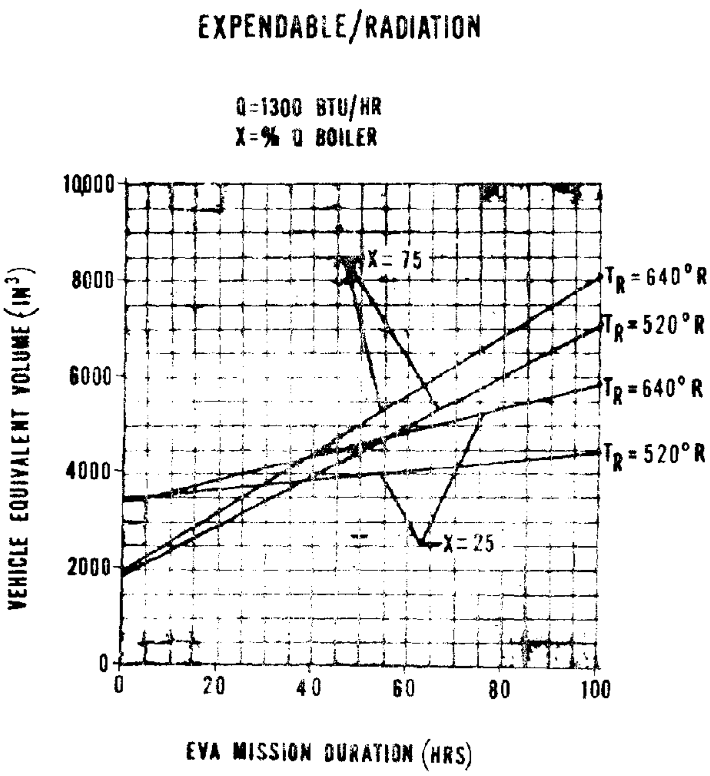
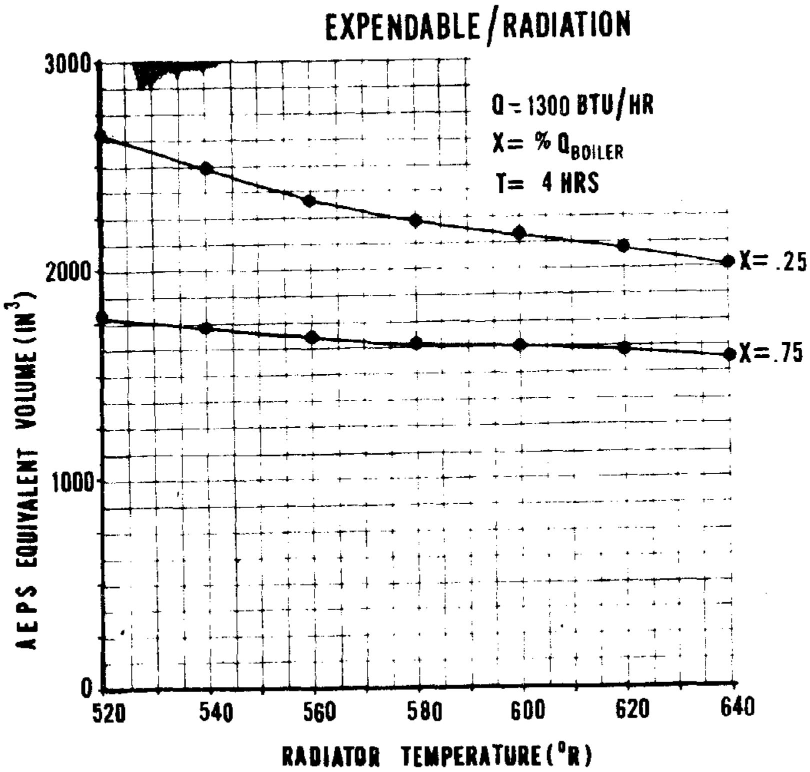
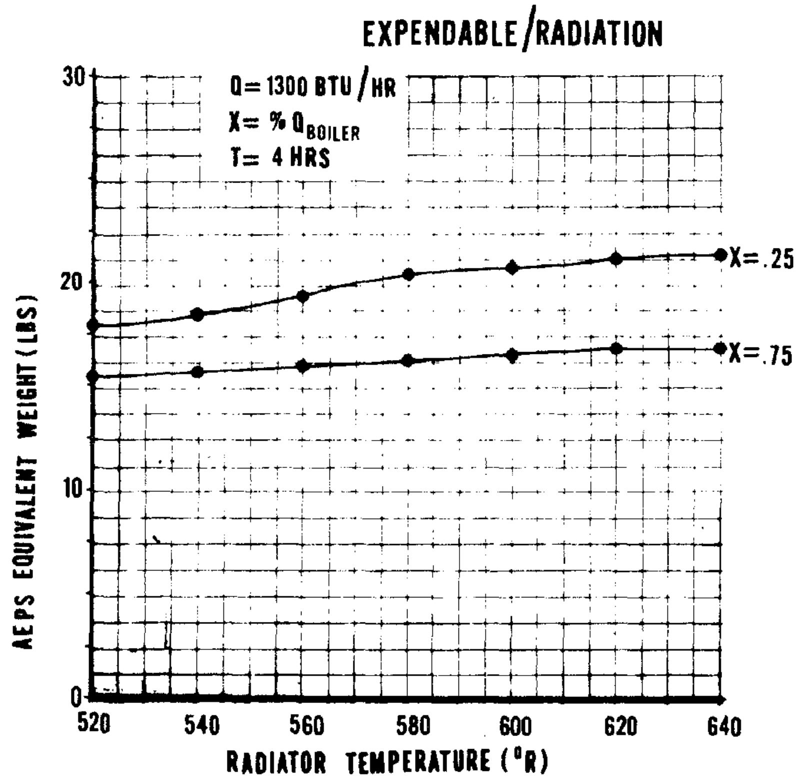


FIGURE 4-40. EXPENDABLE/RADIATION


EXPENDABLE/RADIATION
Q=1300 BTU/HR
X=% Q BOILER
X= 75
T_R= 640°R
T_R= 520°R
T_R= 640°R
T_R=520°R
X= 25
VEHICLE EQUIVALENT WEIGHT (LBS)
TOTAL EVA MISSION TIME (HRS)
0
50
100
0
20
40
60
80
100


EXPENDABLE/RADIATION
Q=1300 BTU/HR
X=% Q BOILER
X= 75
T_R = 640°R
T_R = 520°R
T_R = 640°R
T_R = 520°R
X= 25
VEHICLE EQUIVALENT VOLUME (IN^3)
EVA MISSION DURATION (HRS)
0
2000
4000
6000
8000
10,000
0
20
40
60
80
100


EXPENDABLE/RADIATION
Q = 1300 BTU/HR
X = % Q BOILER
T = 4 HRS
X = .25
X = .75
3000
2000
1000
0
520
540
560
580
600
620
640
AEPS EQUIVALENT VOLUME (IN³)
RADIATOR TEMPERATURE (°R)


EXPENDABLE/RADIATION
Q = 1300 BTU/HR
X = % Q BOILER
T = 4 HRS
X = .25
X = .75
30
20
10
0
520
540
560
580
600
620
640
AEPS EQUIVALENT WEIGHT (LBS)
RADIATOR TEMPERATURE (°R)

CONCEPT 6 - EXPENDABLE/THERMAL STORAGE (PH_4Cl)

This hybrid concept utilizes a water boiler in parallel with a PH_4Cl thermal storage unit via an LCG temperature control valve. The temperature control valve selects what percentage of the heat load from the LCG is shared by each subsystem, the intention being that the PH_4Cl thermal storage unit handles the average heat load and the water boiler handles peak loads. By doing this, compressor power and expendable water are minimized.

The water boiler provides humidity control by cooling the vent loop which feeds the separated water to the boiler via the water separator to provide additional cooling capacity. A variable speed compressor and variable expansion valve are utilized in the thermal storage subsystem to prevent over-cooling under low or no load conditions. This system is flexible in that it can be sized for a multitude of thermal load sharing combinations. As is the case in the PH_4Cl thermal storage concept, research and development is required on PH_4Cl and its thermal storage unit configuration.

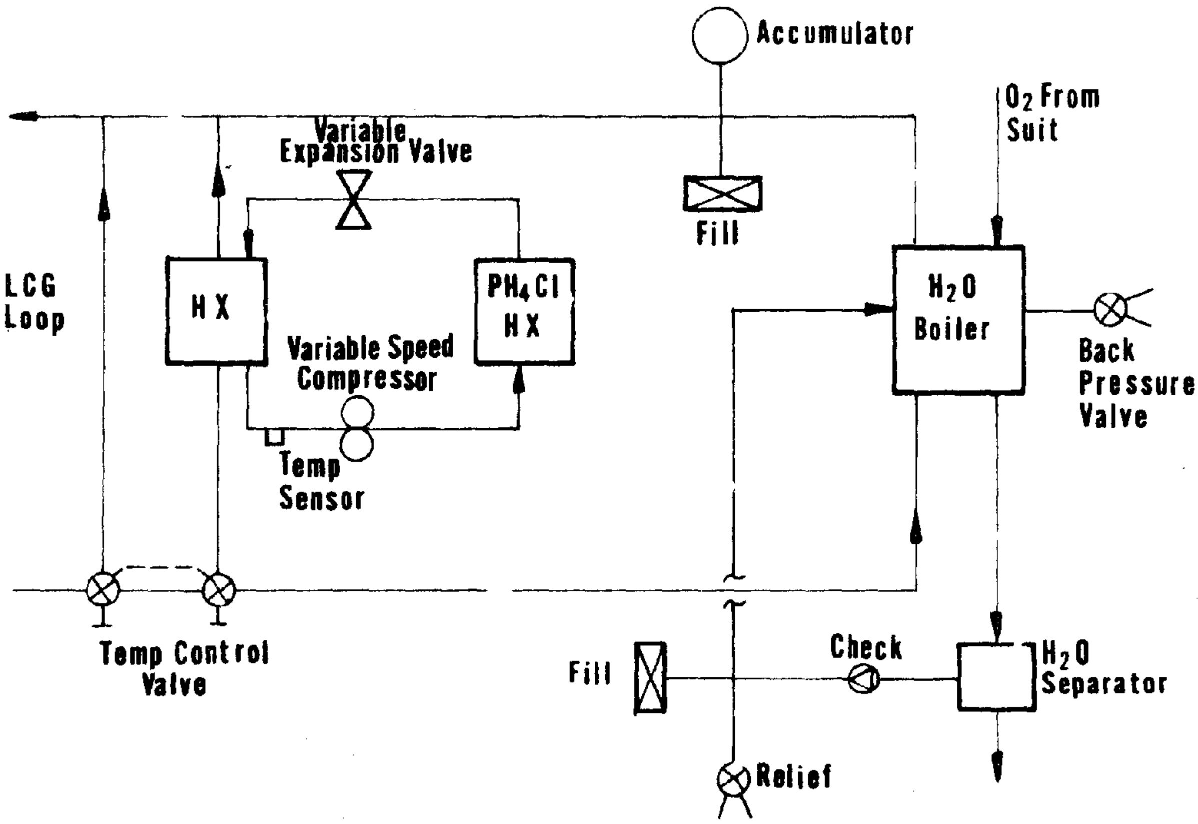
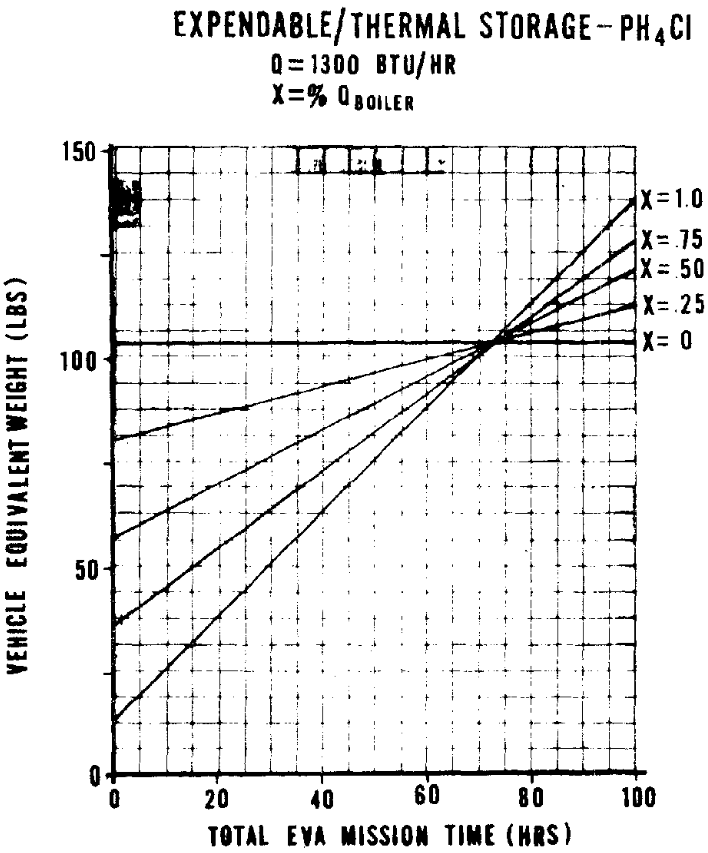
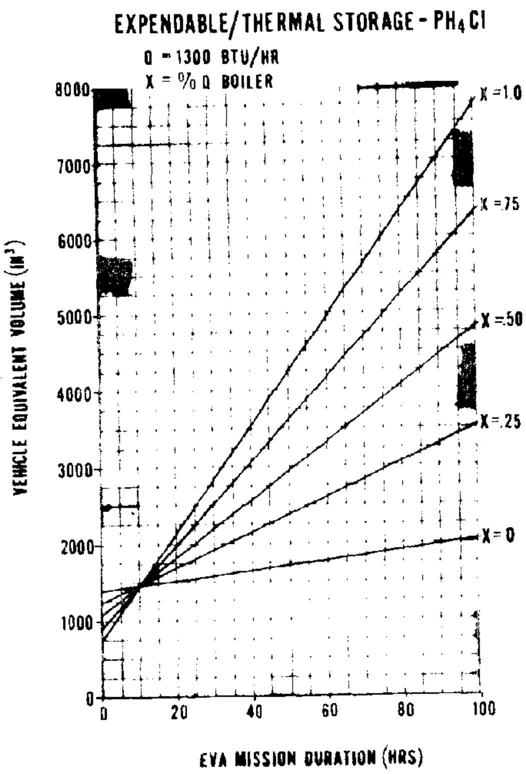
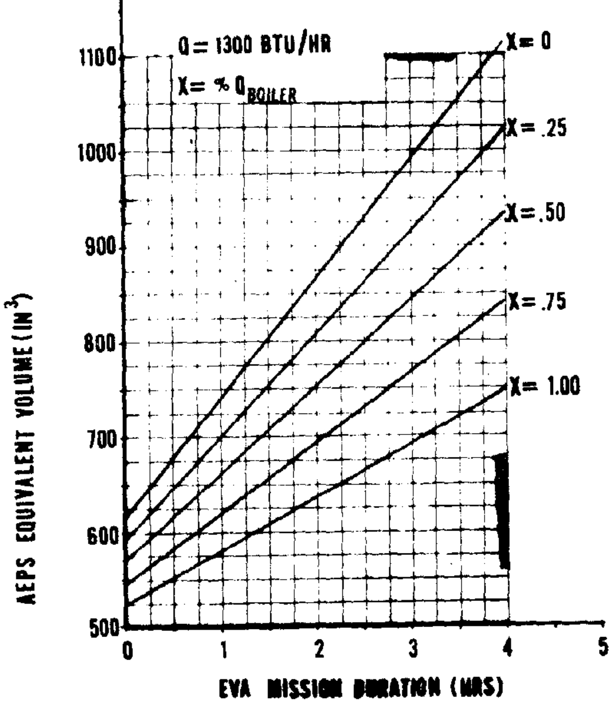


FIGURE 4-41. EXPENDABLE/THERMAL STORAGE – PH_4Cl

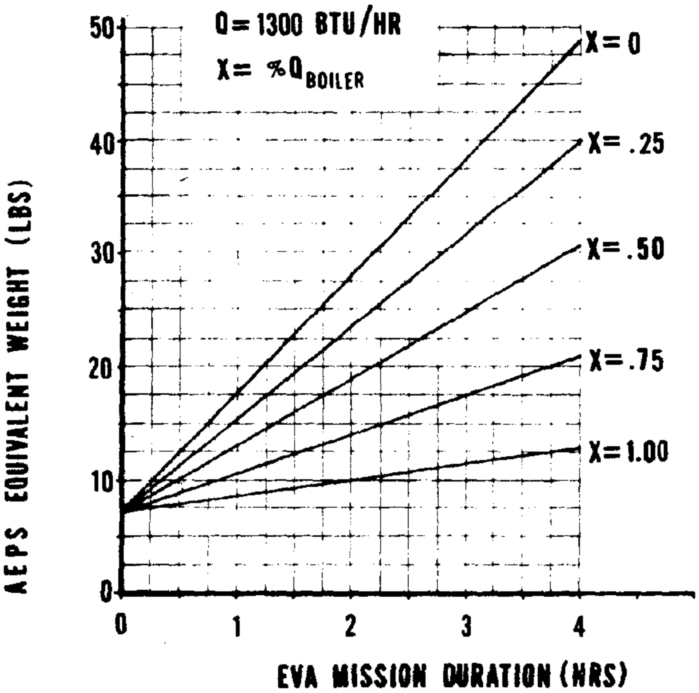

EXPENDABLE/THERMAL STORAGE – PH_4Cl
Q = 1300 BTU/HR
X = % Q_{BOILER}
150
100
50
0
0
20
40
60
80
100
TOTAL EVA MISSION TIME (HRS)
VEHICLE EQUIVALENT WEIGHT (LBS)
X = 1.0
X = .75
X = .50
X = .25
X = 0


EXPENDABLE/THERMAL STORAGE – PH_4Cl
Q = 1300 BTU/HR
X = % Q BOILER
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
EVA MISSION DURATION (HRS)
VEHICLE EQUIVALENT VOLUME (IN^3)
X = 1.0
X = .75
X = .50
X = .25
X = 0

EXPENDABLE/THERMAL STORAGE - PH_4Cl



EXPENDABLE/THERMAL STORAGE - PH_4Cl



4.2.1.3 CO_2 CONTROL/O_2 SUPPLY

CONCEPT 1 - LITHIUM HYDROXIDE (LiOH)

Lithium hydroxide, a non-regenerable solid absorbent, is packaged in replaceable cartridges which also may contain a particulate filter and activated charcoal for trace contaminant control. The LiOH contains 4 to 8% water and must be stored in protective containers in a temperature controlled environment to ensure maximum performance.

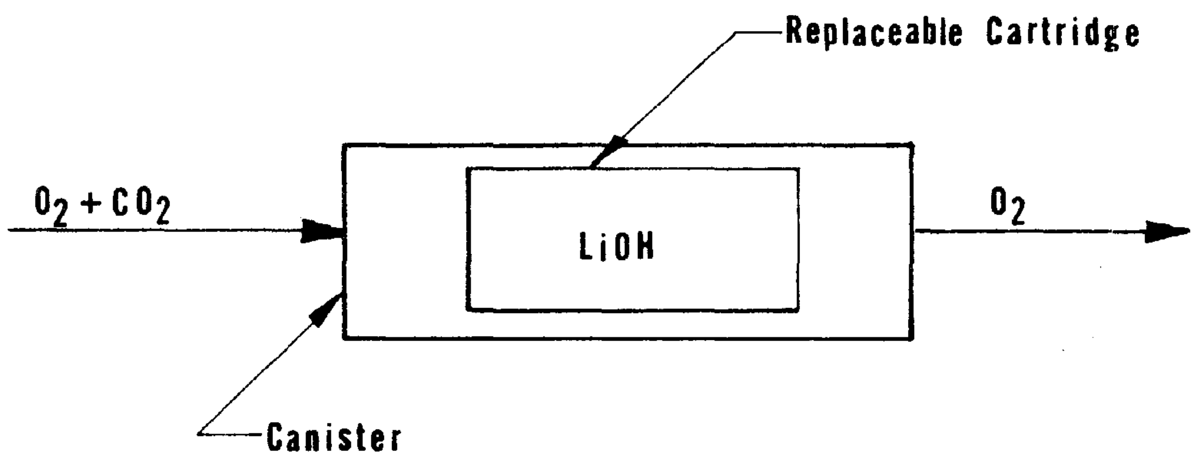
After each use, the cartridge is replaced in the canister regardless of the total time or use rate accumulated on the unit. This procedure ensures a fully operational charge for each mission but has a built-in unrecoverable waste which is the unused portion of the absorbent plus the cartridge (unless the used cartridge is then utilized in the vehicle ECS). In use, the vent loop returning from the astronaut is directed to the LiOH where the following reactions occur:

$$LiOH + H_2O(g) \longrightarrow LiOH\ H_2O$$

$$2\ LiOH\ H_2O + CO_2 \longrightarrow Li_2CO_3 + 3H_2O(g)$$

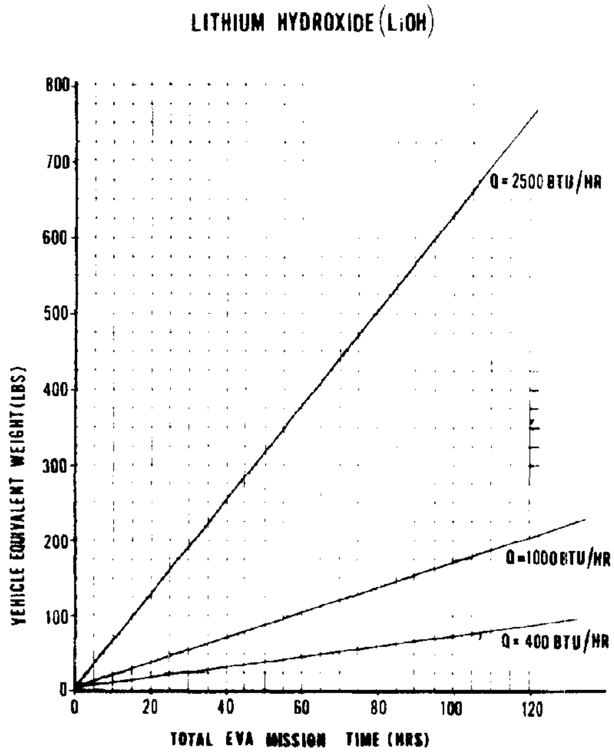
$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O(g)$$

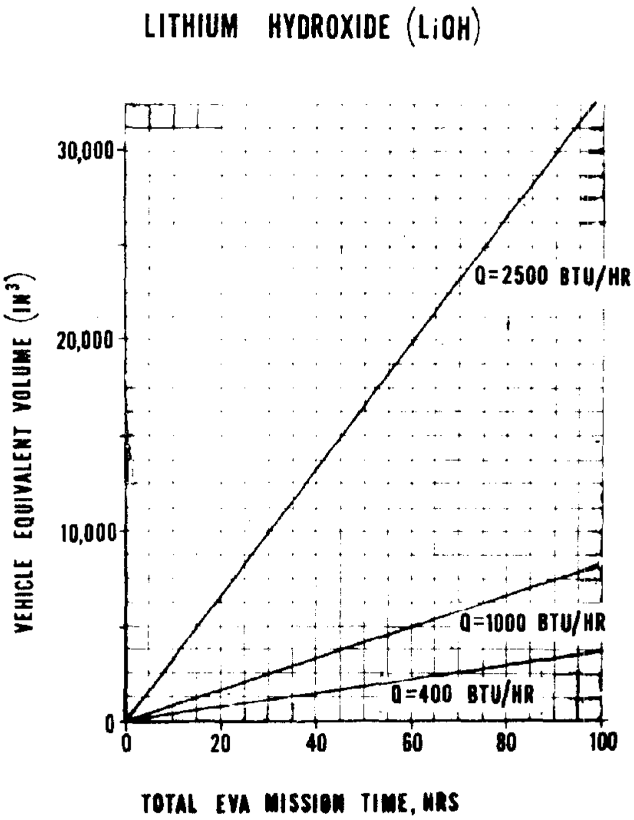
There is a net energy and water vapor production in the process which is removed in the thermal/humidity control subsystem. Outlet CO_2 concentration remains near zero for almost 80% of the useful life, thus providing the astronaut an extremely low time-averaged CO_2 atmosphere. The following curves are based on a LiOH utilization efficiency of 57% at an average metabolic load of 1000 BTU/hr.

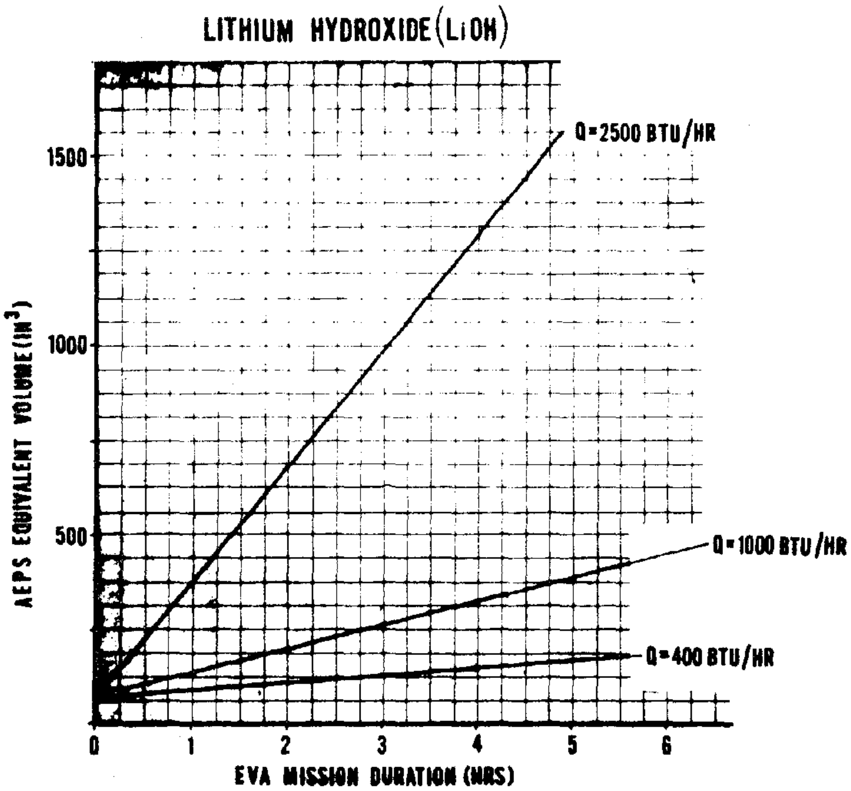


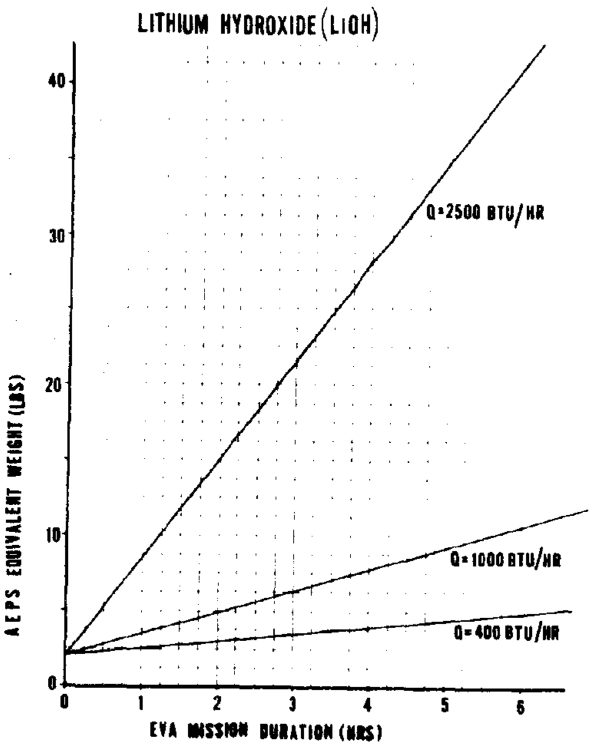
$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

FIGURE 4–42. LITHIUM HYDROXIDE (LiOH)


LITHIUM HYDROXIDE (LiOH)
VEHICLE EQUIVALENT WEIGHT (LBS)
800
700
600
500
400
300
200
100
0
Q = 2500 BTU/HR
Q = 1000 BTU/HR
Q = 400 BTU/HR
0
20
40
60
80
100
120
TOTAL EVA MISSION TIME (HRS)


LITHIUM HYDROXIDE (LiOH)
VEHICLE EQUIVALENT VOLUME (IN³)
30,000
20,000
10,000
0
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
20
40
60
80
100
TOTAL EVA MISSION TIME, HRS


LITHIUM HYDROXIDE (LiOH)
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
1500
1000
500
0
1
2
3
4
5
6
AEPS EQUIVALENT VOLUME (IN³)
EVA MISSION DURATION (HRS)


LITHIUM HYDROXIDE (LiOH)
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
40
30
20
10
0
1
2
3
4
5
6
AEPS EQUIVALENT WEIGHT (LBS)
EVA MISSION DURATION (HRS)

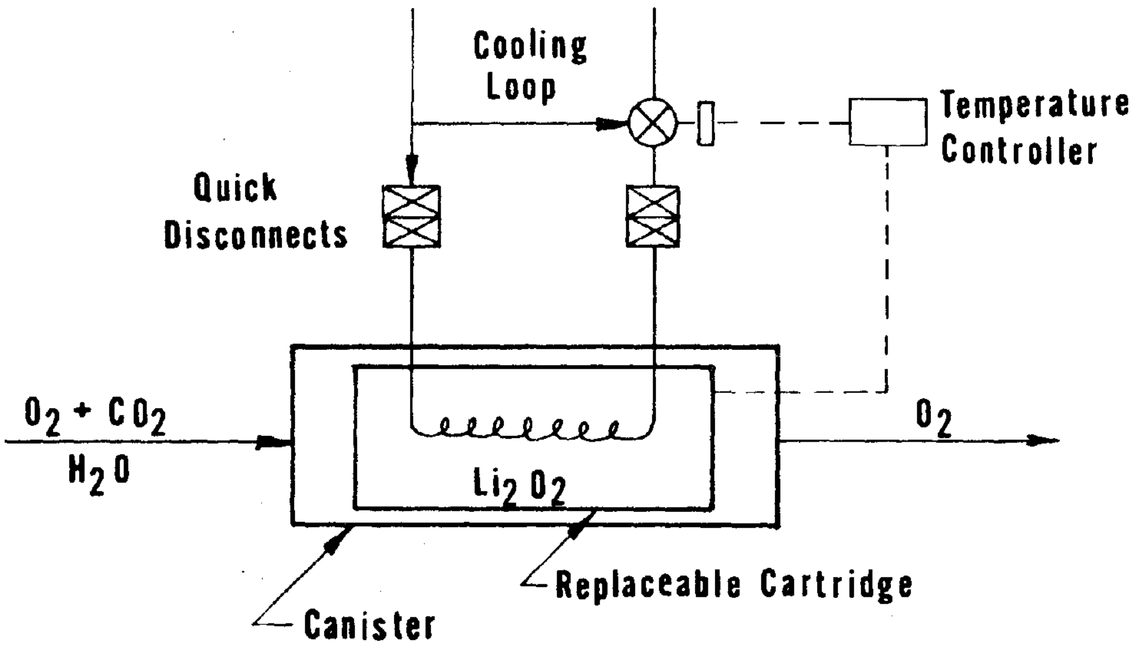
CONCEPT 2 - LITHIUM PEROXIDE (Li_2O_2)

Lithium peroxide, Li_2O_2, reacts with water vapor and CO_2 according to the following reactions:

$$Li_2O_2 + H_2O \longrightarrow 2\,LiOH + 1/2\,O_2$$
$$LiOH + H_2O \longrightarrow LiOH \cdot H_2O$$
$$2\,LiOH \cdot H_2O + CO_2 \longrightarrow Li_2CO_3 + 3\,H_2O$$
$$Li_2O_2 + CO_2 \longrightarrow Li_2CO_3 + 1/2\,O_2$$

A non-regenerable solid absorbent, Li_2O_2 is supplied in cartridges which are replaced after each mission. In addition to CO_2 control, the chemical provides approximately one-half the metabolic oxygen requirement. Temperature control of the reacting bed is necessary to obtain acceptable performance over widely varying metabolic rates. Over-cooling minimizes oxygen production while under-cooling can result in excessive O_2 production and poor CO_2 control. The addition of catalysts has been shown to be effective in stimulating O_2 production at lower temperatures.

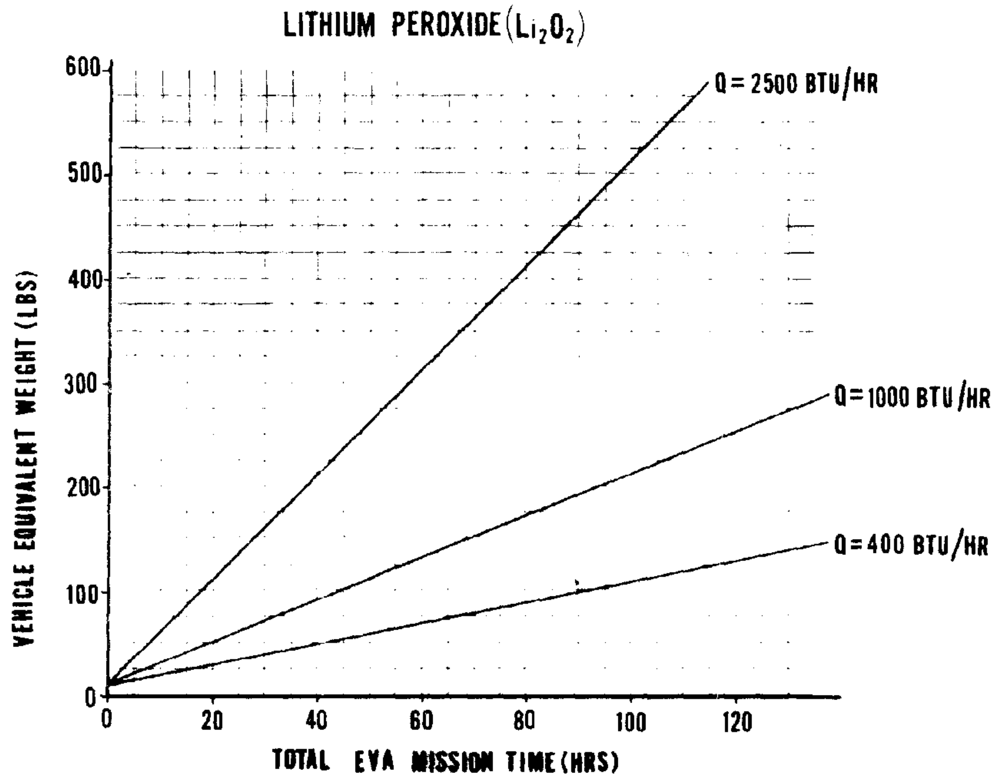
Usefulness of the concept is hindered by the low (relative to LiOH) chemical density and the requirement for cooling and subsequent temperature control. In a manner similar to cooled LiOH, Li_2O_2 is advantageous at high metabolic loads where performance degradation of uncooled LiOH is most rapid. The following curves are baded on a Li_2O_2 utilization efficiency of 58% at an average metabolic load of 1000 BTU/hr.

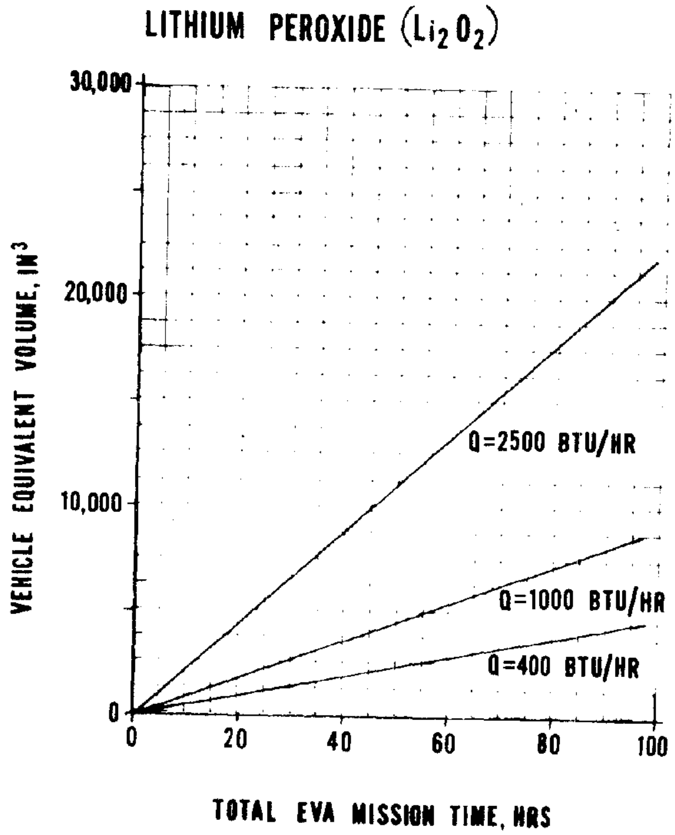


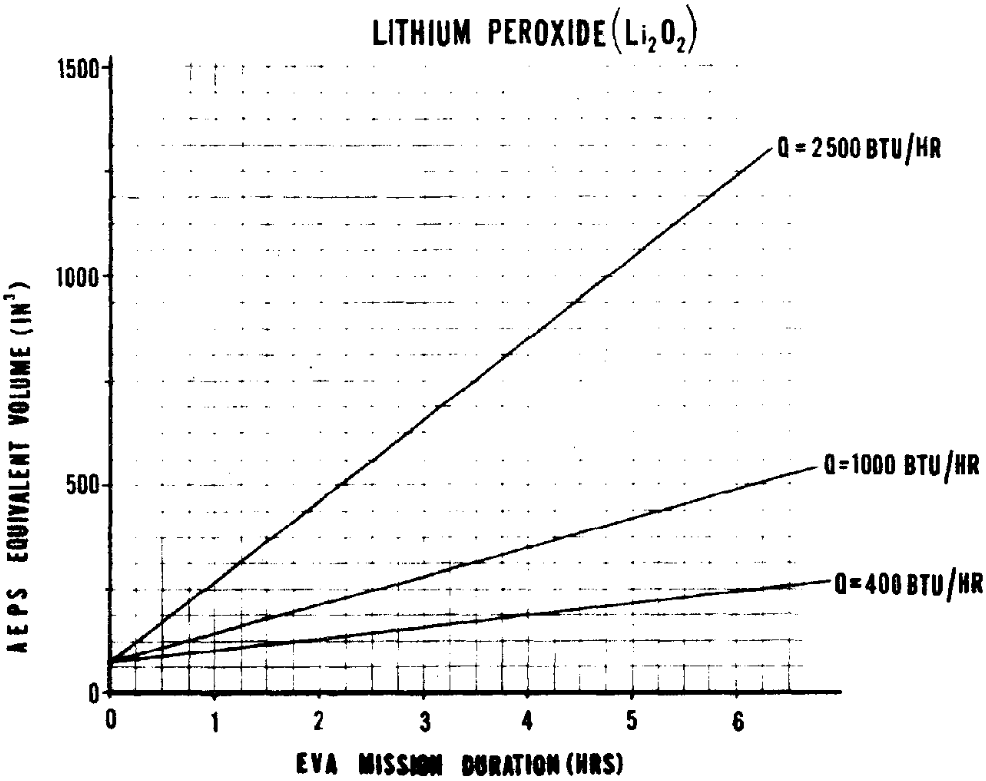
$$Li_2O_2 + H_2O \longrightarrow 2LiOH + O_2 + Q$$

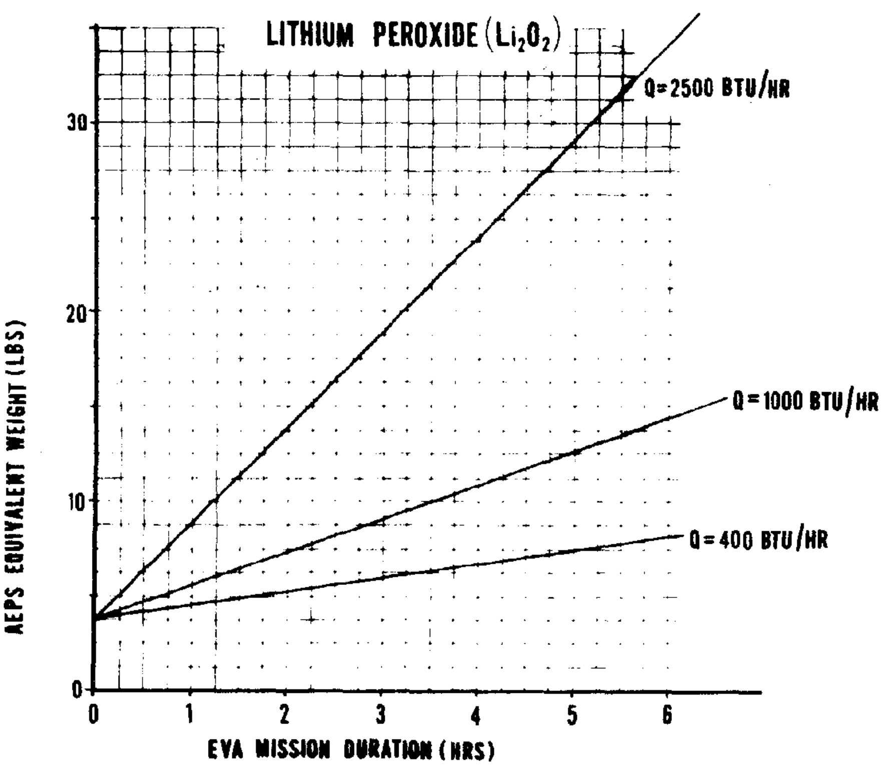
$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

FIGURE 4–43. LITHIUM PEROXIDE (Li_2O_2)


LITHIUM PEROXIDE(Li_2O_2)
VEHICLE EQUIVALENT WEIGHT (LBS)
600
500
400
300
200
100
0
0
20
40
60
80
100
120
TOTAL EVA MISSION TIME (HRS)
Q = 2500 BTU/HR
Q = 1000 BTU/HR
Q = 400 BTU/HR


LITHIUM PEROXIDE (Li_2O_2)
VEHICLE EQUIVALENT VOLUME, IN^3
30,000
20,000
10,000
0
0
20
40
60
80
100
TOTAL EVA MISSION TIME, HRS
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR


LITHIUM PEROXIDE (Li_2O_2)
1500
1000
500
0
Q = 2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
AEPS EQUIVALENT VOLUME (IN^3)
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)


LITHIUM PEROXIDE (Li_2O_2)
30
20
10
0
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
AEPS EQUIVALENT WEIGHT (LBS)
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)

CONCEPTS 3 & 5 - METALLIC OXIDE (AEPS REGENERABLE)

A variation of the metallic oxide concept is a cyclic or AEPS regenerable configuration. Two beds, similar in design to that described for the vehicle regenerable system, are provided, each containing electrical elements for regeneration and a cooling loop to cool the regenerated bed and maintain temperature control during operation.

A timer is provided to sequence the vent loop and coolant loop valves to allow the vent loop and coolant loop to flow to the on stream bed and to heat and expose to space vacuum the regenerating bed.

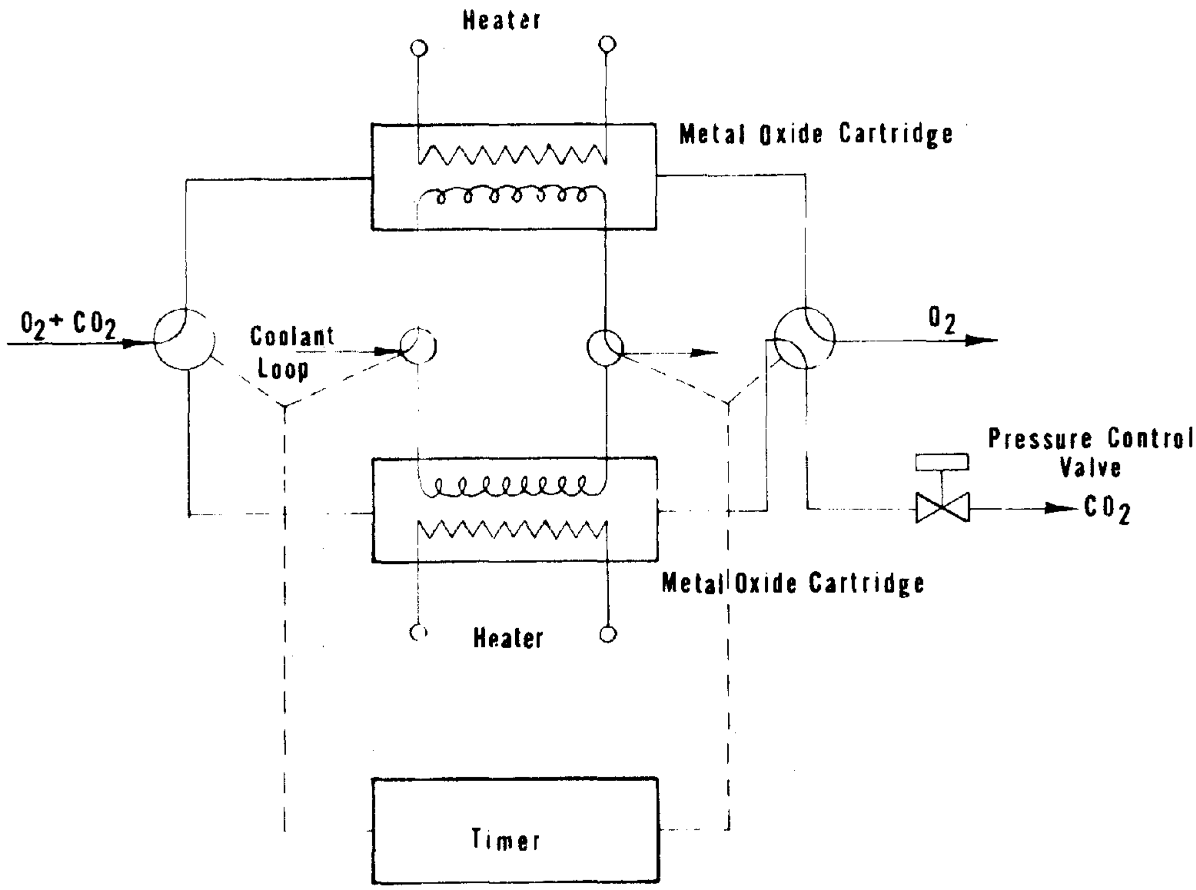
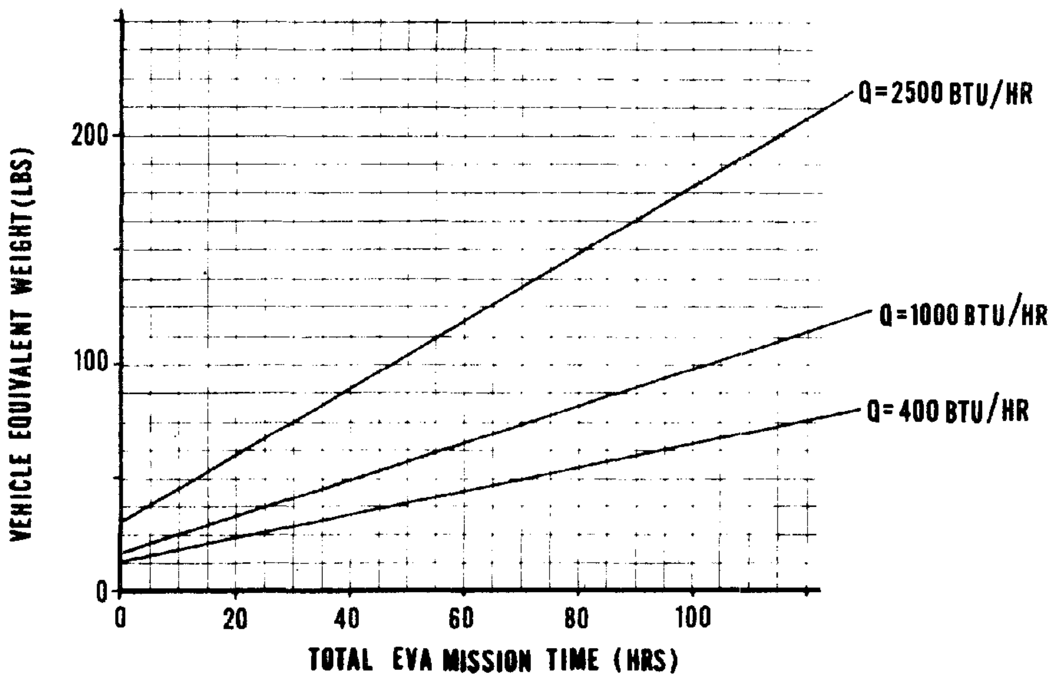
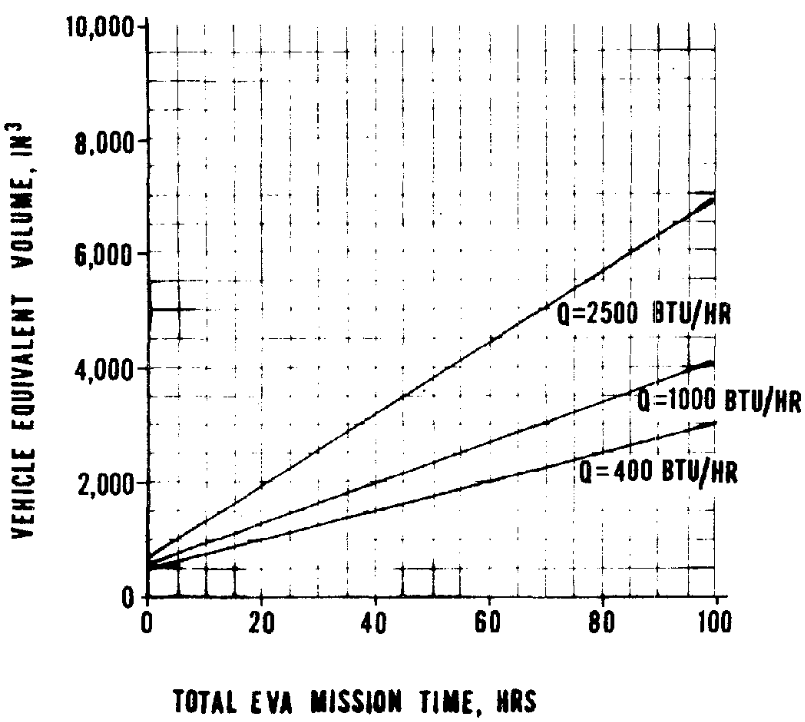


FIGURE 4–44. METALLIC OXIDE – AEPS REGENERABLE

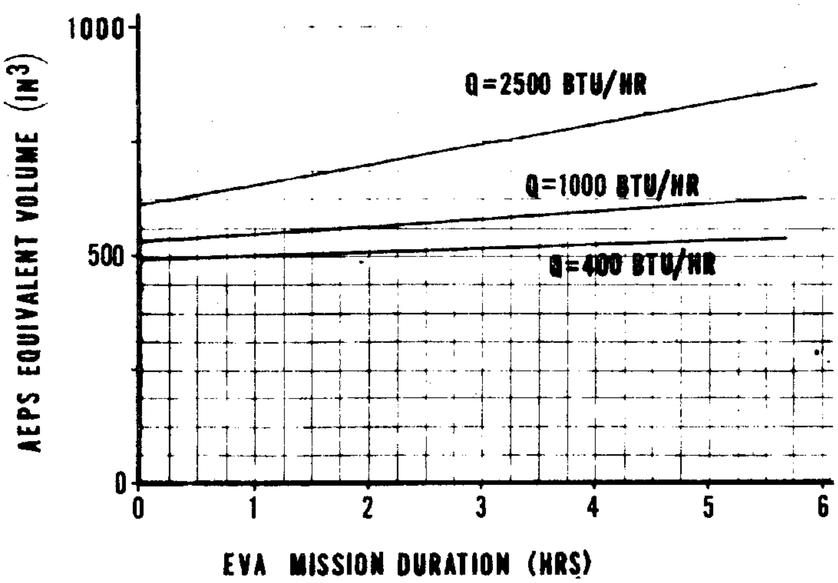
ZINC OXIDE (ZnO) - AEPS REGENERABLE



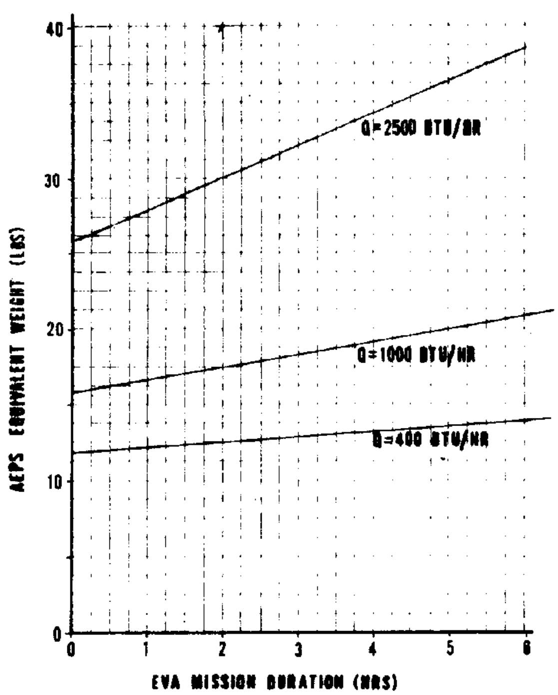
ZINC OXIDE (ZnO)-AEPS REGENERABLE



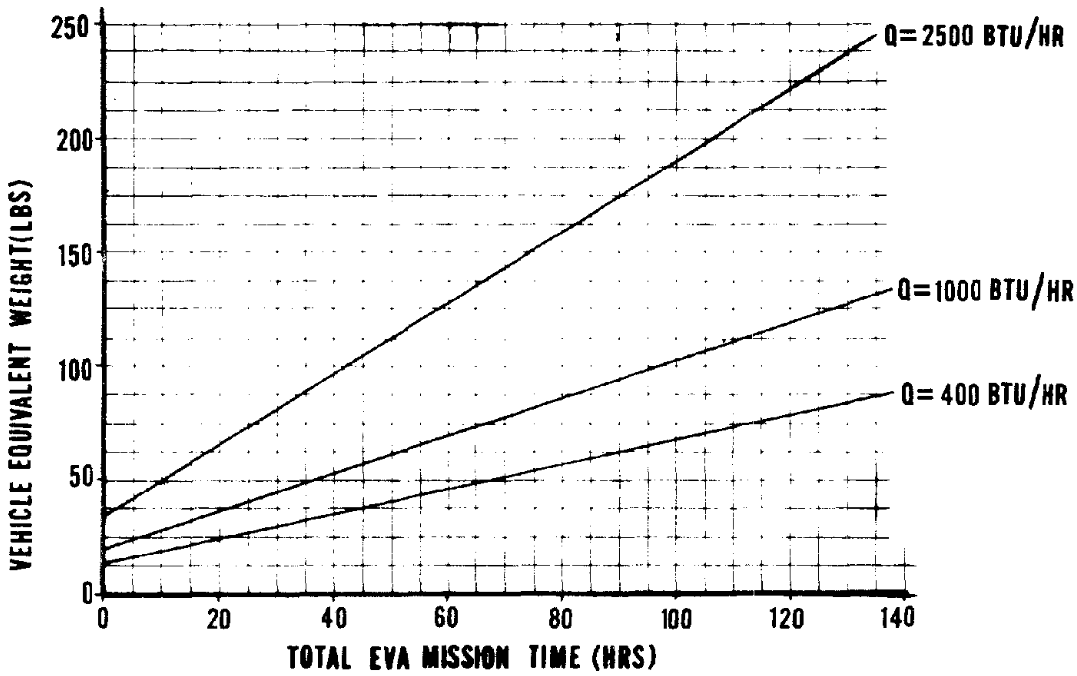
ZINC OXIDE (ZnO)-AEPS REGENERABLE



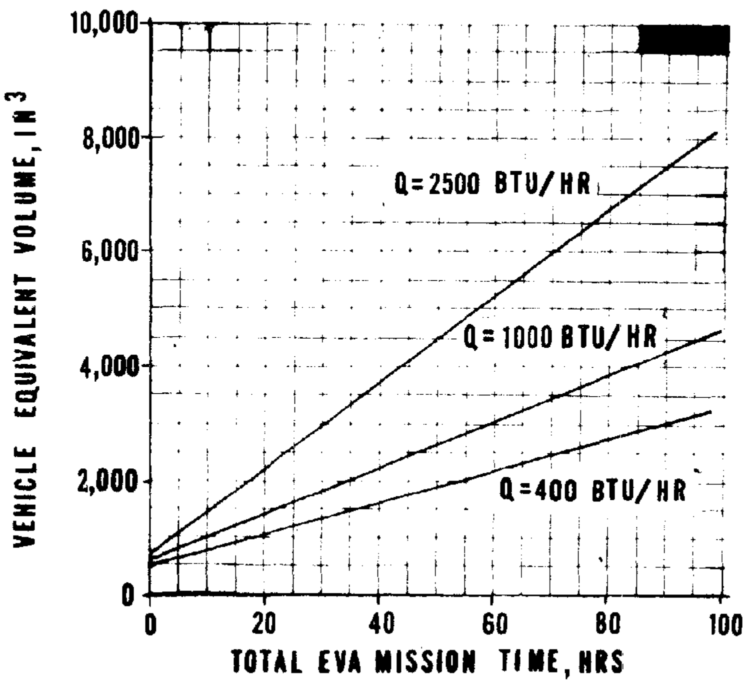
ZINC OXIDE (ZnO)—AEPS REGENERABLE

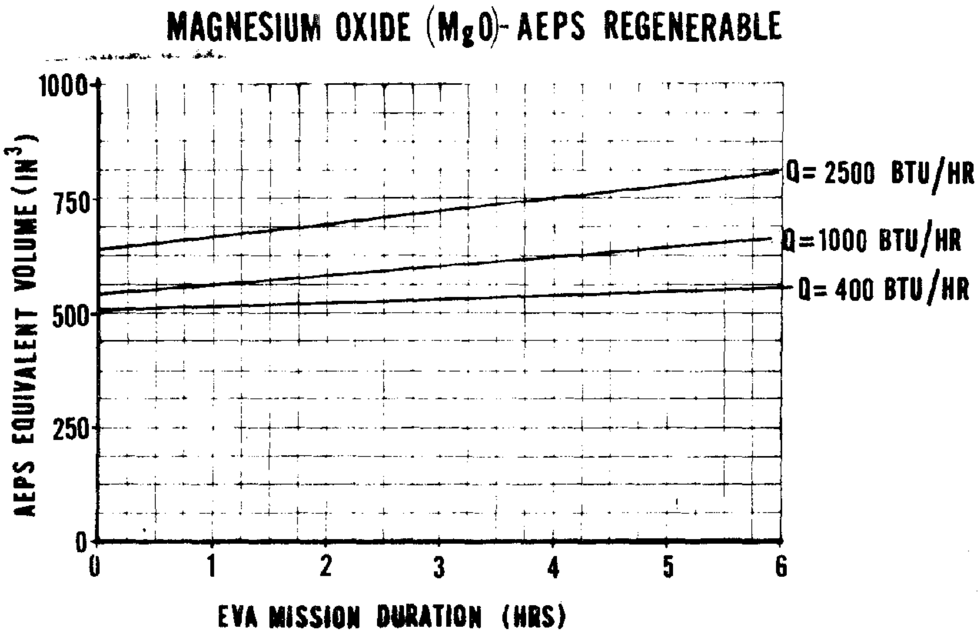


MAGNESIUM OXIDE (MgO)-AEPS REGENERABLE

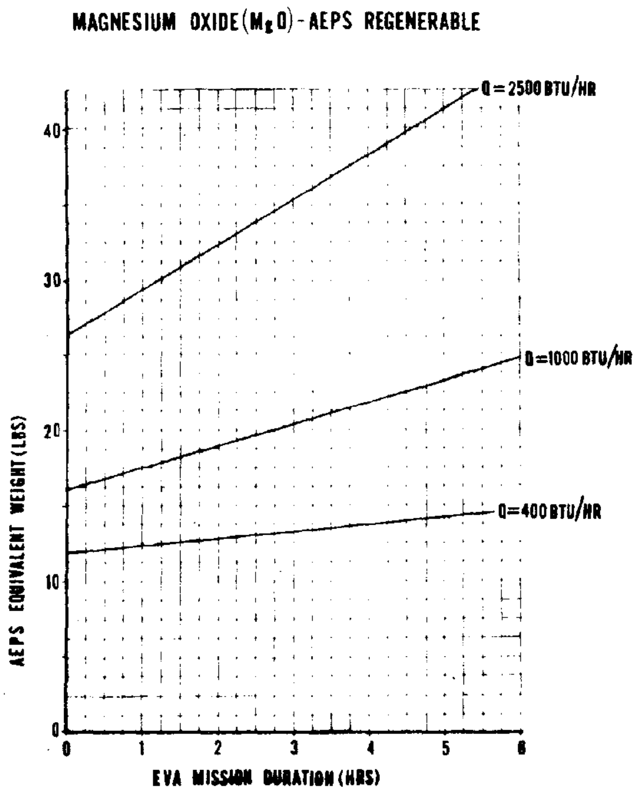


MAGNESIUM OXIDE (Mg O) -AEPS REGENERABLE





MAGNESIUM OXIDE (MgO)-AEPS REGENERABLE
1000
750
500
250
0
AEPS EQUIVALENT VOLUME (IN³)
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)
Q= 2500 BTU/HR
Q=1000 BTU/HR
Q= 400 BTU/HR



MAGNESIUM OXIDE (MgO) - AEPS REGENERABLE
40
30
20
10
0
AEPS EQUIVALENT WEIGHT (LBS)
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR

CONCEPTS 4 & 6 - METALLIC OXIDE (VEHICLE REGENERABLE)

Metallic oxides (i.e. ZnO, MgO) react with CO_2 according to the following reversible reaction:

$$MO + CO_2 \rightleftharpoons MCO_3 + Q$$

As shown in Figure 4-23, the carbonate readily decomposes with increasing temperature and, in some cases, may be solely vacuum regenerable.

Excessive volume change during the adsorb/desorb cycle affects the chemical's physical stability and is a prime consideration in any future development effort. For this study, the adsorbent was contained between screens with gas flow over rather than through the packing. CO_2 diffusion into the thin oxide bed will be sufficient as long as the solid volume transition during adsorb/desorb does not result in an impregnable surface or if an extremely fine screen is not required. An alternate concept would consider a carrier to stabilize the solid adsorbent -- possibly a thin layer of the oxide flame-sprayed on a screen matrix.

In the vehicle regenerable configuration, the adsorbent is packaged in a cartridge which is replaced after each mission. An oven/vacuum chamber will be provided within the vehicle for cartridge regeneration. Although not considered in the evaluation, reclamation of the oxygen is possible with this system by directing the desorbed gas to the vehicle CO_2 reduction system.

Other advantages of the concept include the visual inspection of the packed beds after each use and simple replacement, should it be required. Parametric data for CO_2 control/O_2 supply subsystems utilizing magnesium oxide (MgO) and zinc oxide (ZnO) to provide CO_2 control are presented on the following pages and are based on a utilization efficiency of 50% at an average metabolic load of 1000 BTU/hr.

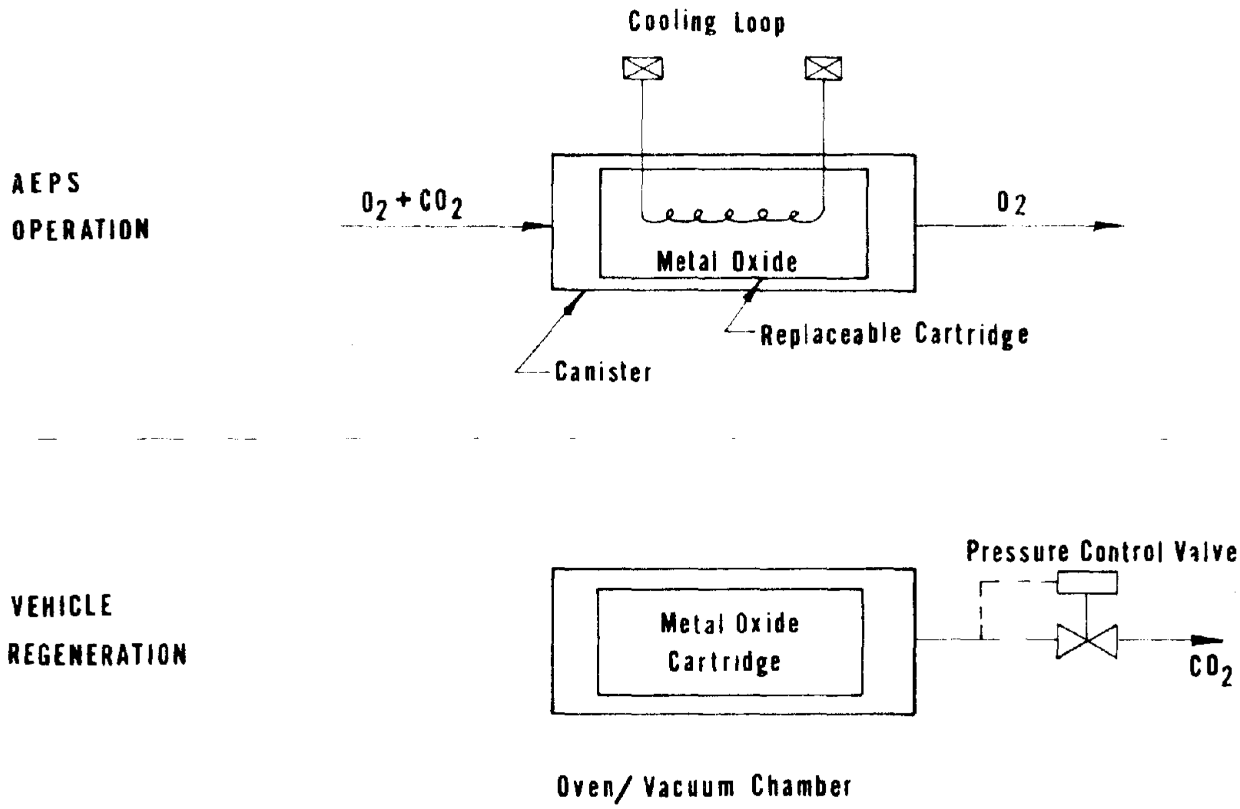
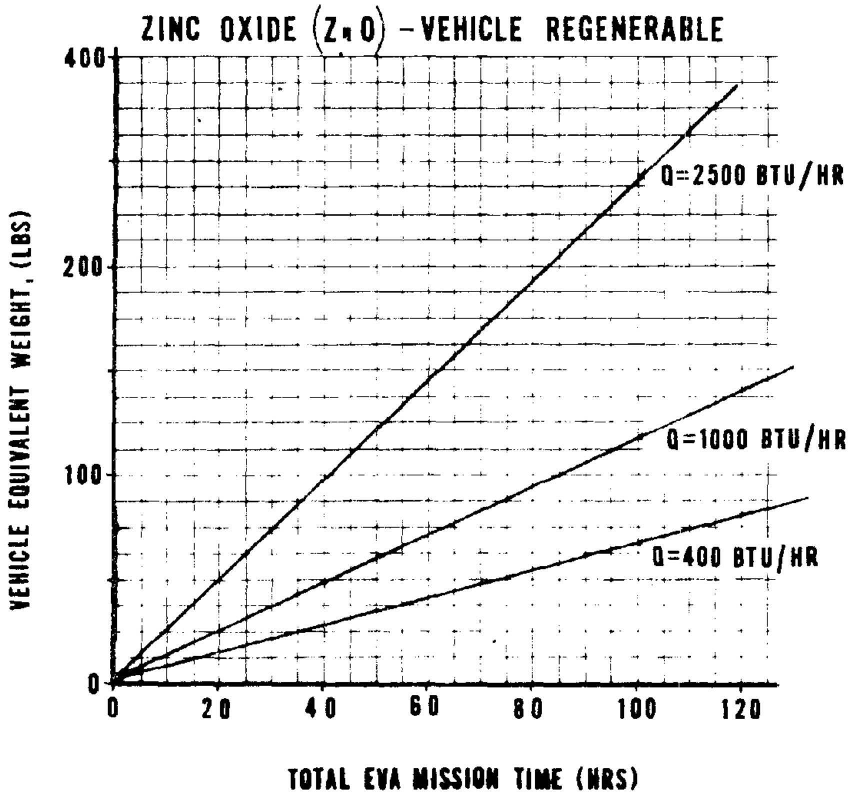
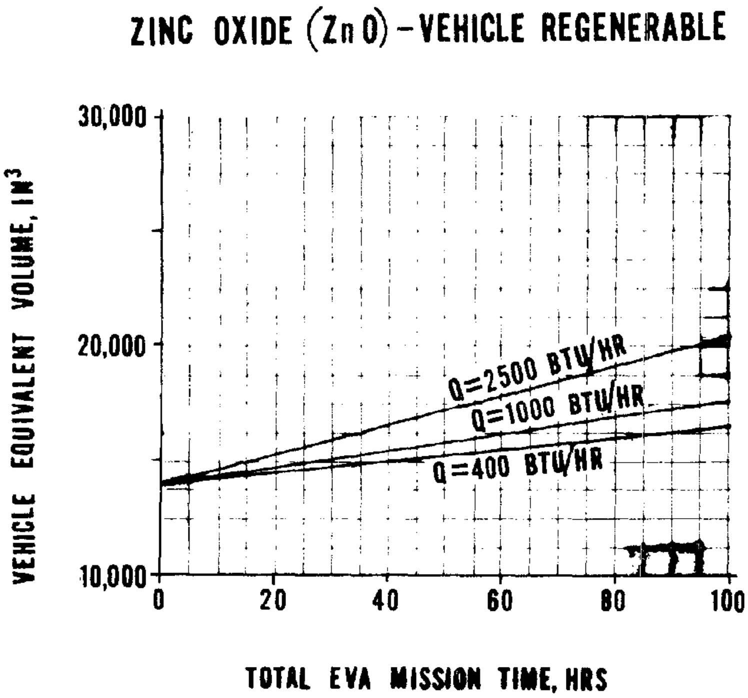
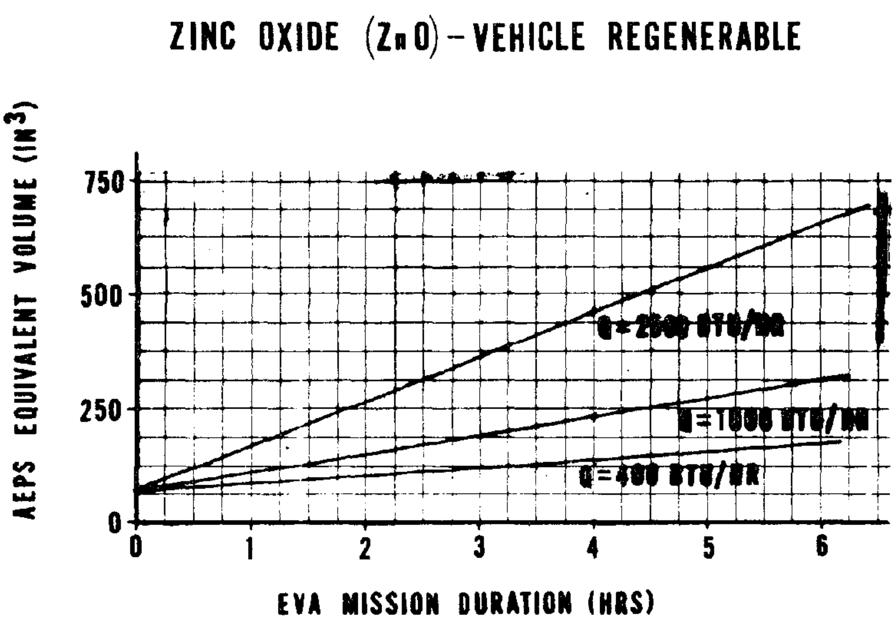
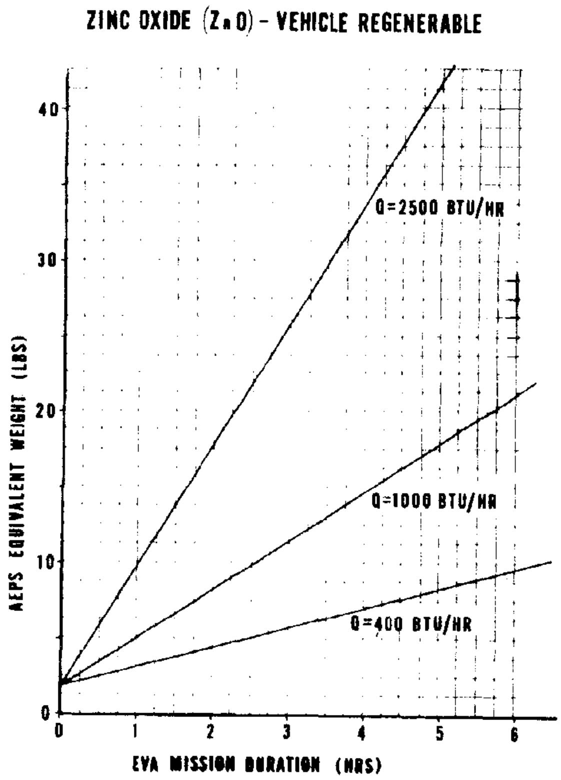


FIGURE 4–45. METALLIC OXIDE – VEHICLE REGENERABLE

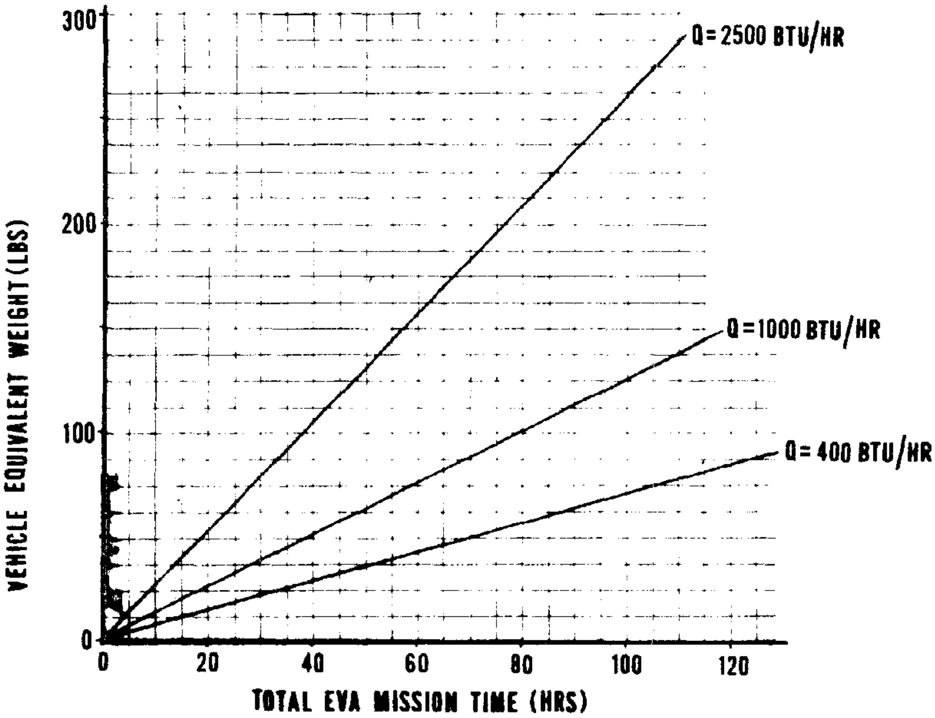

ZINC OXIDE (ZnO) - VEHICLE REGENERABLE
VEHICLE EQUIVALENT WEIGHT, (LBS)
400
200
100
0
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
20
40
60
80
100
120
TOTAL EVA MISSION TIME (HRS)


ZINC OXIDE (ZnO) - VEHICLE REGENERABLE
VEHICLE EQUIVALENT VOLUME, IN³
30,000
20,000
10,000
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
20
40
60
80
100
TOTAL EVA MISSION TIME, HRS

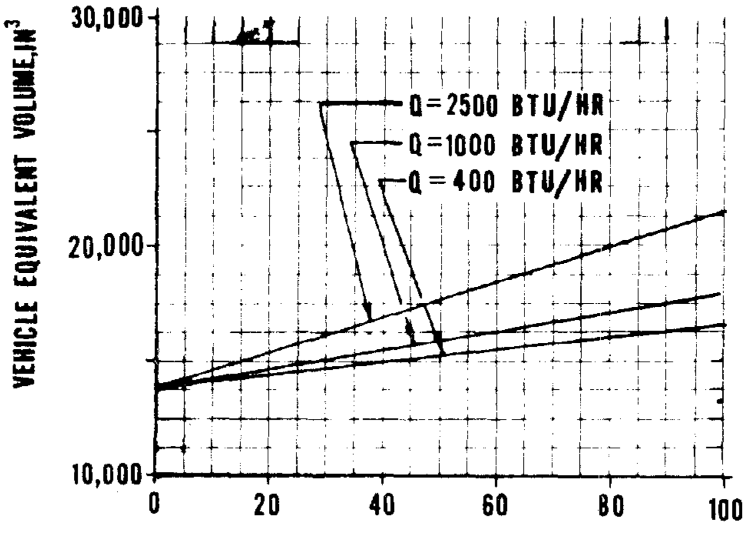

ZINC OXIDE (ZnO) - VEHICLE REGENERABLE
AEPS EQUIVALENT VOLUME (IN³)
750
500
250
0
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)


ZINC OXIDE (ZnO) - VEHICLE REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
40
30
20
10
0
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)

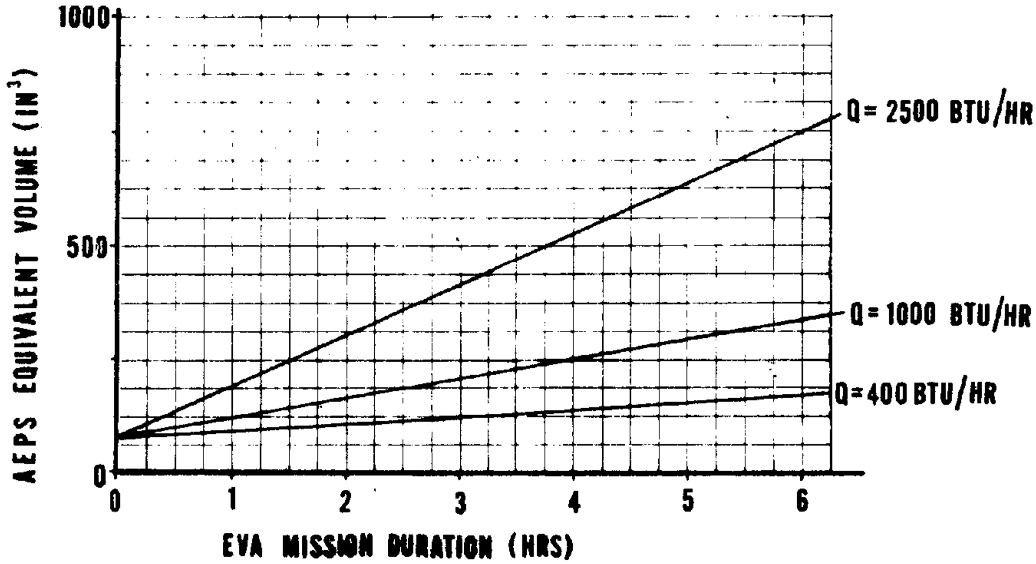
MAGNESIUM OXIDE (MgO) - VEHICLE REGENERABLE



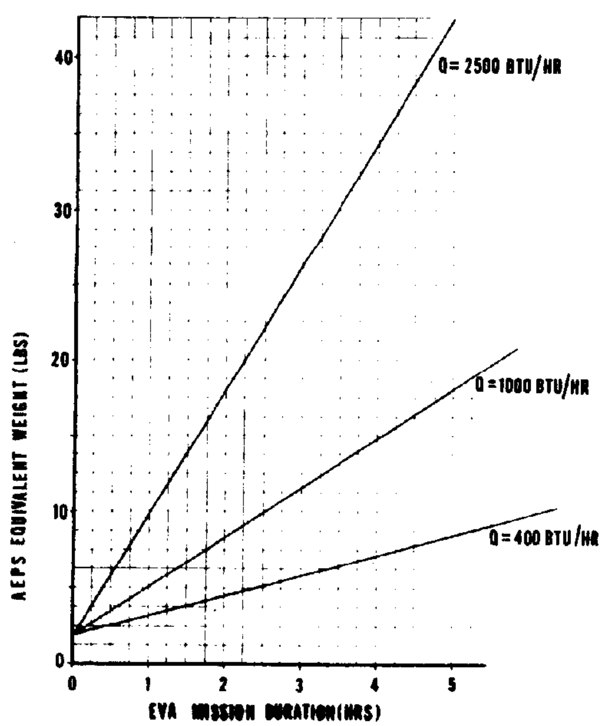
MAGNESIUM OXIDE (MgO) -VEHICLE REGENERABLE



MAGNESIUM OXIDE (MgO) - VEHICLE REGENERABLE



MAGNESIUM OXIDE (MgO) - VEHICLE REGENERABLE



CONCEPT 7 - METAL HYDROXIDE - VEHICLE REGENERABLE

This concept combines the attributes of the lithium hydroxide and metal oxide systems to provide a regenerable sorbent system with high capacity and rate of reaction. Metal hydroxides (i.e. $Z_n\,(OH)_2$, $Mg\,(OH)_2$) react with CO_2 according to the following reaction:

$$M(OH)_2 + CO_2 \longrightarrow MCO_3 + H_2O + Q$$

The process is reversible thru the following reaction steps:

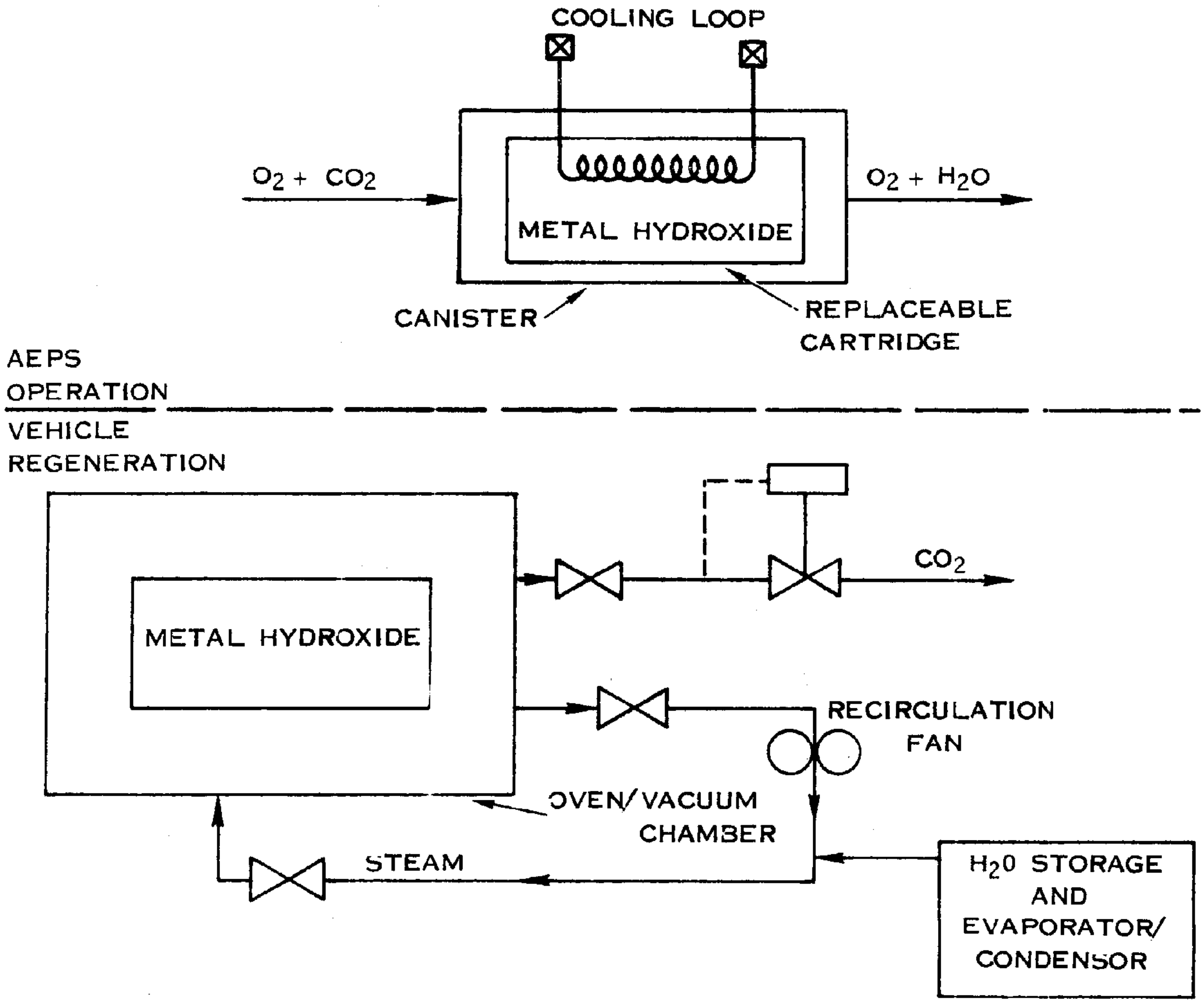
$$MCO_3 + Q \longrightarrow MO + CO_2$$

$$MO + H_2O \longrightarrow M(OH)_2 + Q$$

Higher reaction rates and greater affinity are anticipated using the more basic hydroxides rather than the oxides. This potentially will produce a greater deliverable use capacity but entails a greater load on the humidity control system since water is produced during the CO_2 sorbtion.

Within the AEPS, the sorbent is packaged in a water cooled cartridge which is replaced after each mission. An oven/vacuum chamber is provided in the vehicle for the two step regeneration process. First, under heat and vacuum, the carbonate is calcined to the oxide. Steam is then admitted to the chamber and recirculated at 400 to 900°F, converting the oxide to the hydroxide.

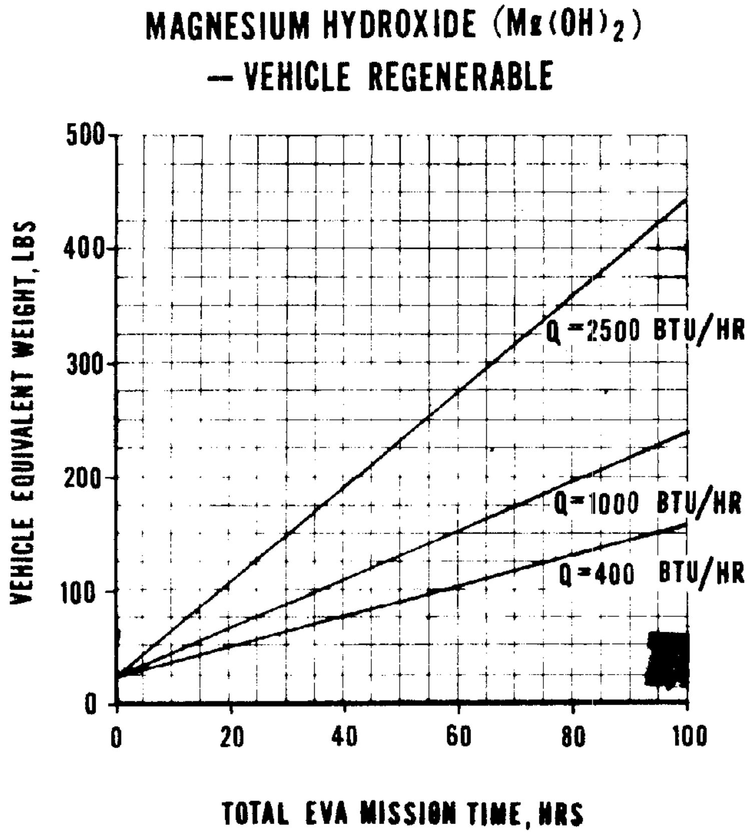
Parametric data for CO_2 control/O_2 supply subsystems utilizing magnesium hydroxide ($Mg\,(OH)_2$) to provide CO_2 control are presented on the following pages and are based on a utilization efficiency of 50% of an average metabolic load of 1000 Btu/hr.

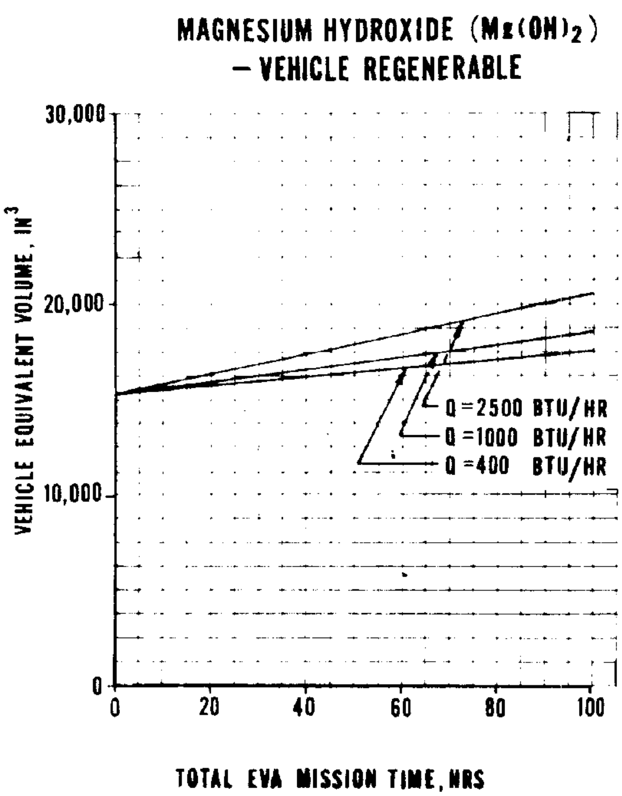


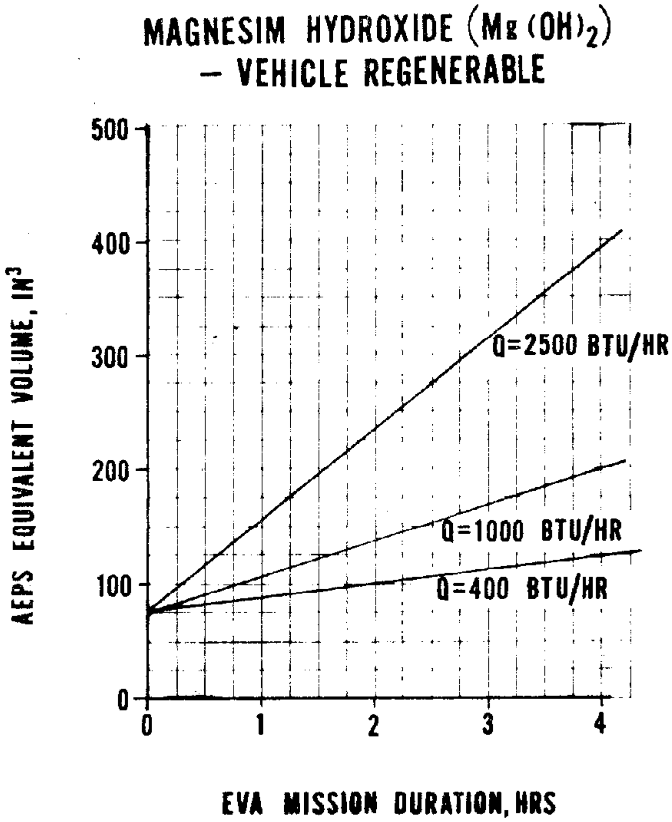
$$MCO_3 \xrightarrow[\text{VACUUM}]{\text{HEAT}} MO + CO_2$$

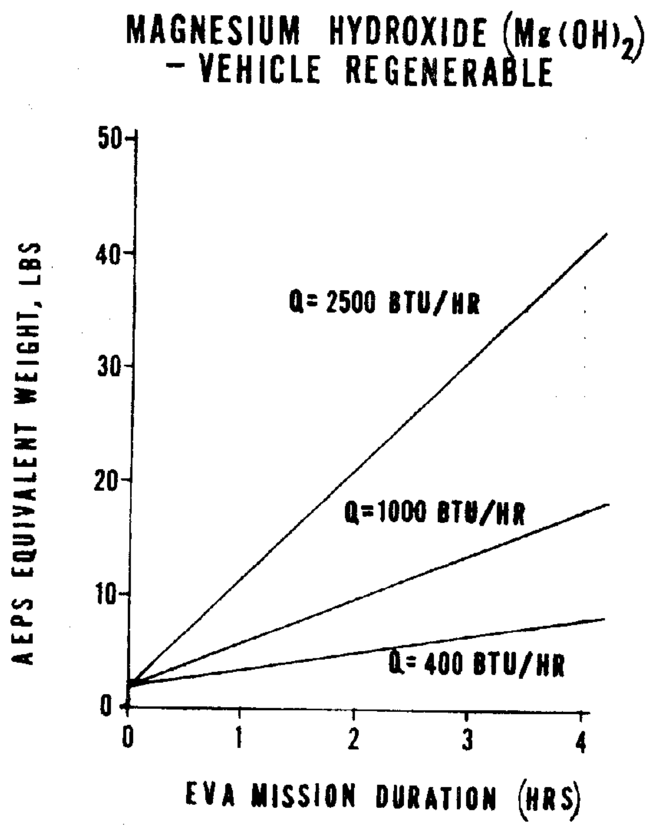
$$MO + H_2O \longrightarrow M(OH)_2$$

FIGURE 4-4ι METAL HYDROXIDE — VEHICLE REGENERABLE


MAGNESIUM HYDROXIDE (Mg(OH)2)
— VEHICLE REGENERABLE
VEHICLE EQUIVALENT WEIGHT, LBS
500
400
300
200
100
0
Q = 2500 BTU/HR
Q = 1000 BTU/HR
Q = 400 BTU/HR
0
20
40
60
80
100
TOTAL EVA MISSION TIME, HRS


MAGNESIUM HYDROXIDE (Mg(OH)2)
— VEHICLE REGENERABLE
VEHICLE EQUIVALENT VOLUME, IN3
30,000
20,000
10,000
0
Q = 2500 BTU/HR
Q = 1000 BTU/HR
Q = 400 BTU/HR
0
20
40
60
80
100
TOTAL EVA MISSION TIME, HRS


MAGNESIM HYDROXIDE (Mg(OH)2)
– VEHICLE REGENERABLE
AEPS EQUIVALENT VOLUME, IN3
EVA MISSION DURATION, HRS
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
500
400
300
200
100
0
1
2
3
4


MAGNESIUM HYDROXIDE (Mg(OH)2)
– VEHICLE REGENERABLE
AEPS EQUIVALENT WEIGHT, LBS
EVA MISSION DURATION (HRS)
Q= 2500 BTU/HR
Q=1000 BTU/HR
Q= 400 BTU/HR
50
40
30
20
10
0
1
2
3
4

CONCEPT 8 - SOLID AMINE - AEPS REGENERABLE

An inert carrier is utilized to provide a stable amine adsorbent bed in this concept. The regenerable solid amine is packaged within the flow passages of a plate-fin matrix similar in design to an extended surface compact heat exchanger. Alternate flow passages contain adsorbing and desorbing material with the unique feature of an isothermal process. Energy released from the adsorbing passages is transferred by conduction through the metal matrix to the desorbing material to supply the requirements of the endothermic desorption. This concept neither imposes a thermal load on the AEPS nor requires energy for regeneration. A timer and valving is provided to cycle the packed beds from the on-line adsorb to the space vacuum desorb cycle.

Further development is required in the adsorbent, however, to find application within the AEPS system. Current materials possess an affinity for water that would excessively dehumidify the ventilation loop. This loss of water vapor could not only cause astronaut discomfort, but may also reduce the adsorbent's capacity for CO_2 and thus result in poor CO_2 control. This problem has been recognized and solutions have been proposed to alter the amine and to minimize its affinity for water.

The following curves are based on a 2% CO_2 capacity of the solid amine plus the inert carrier.

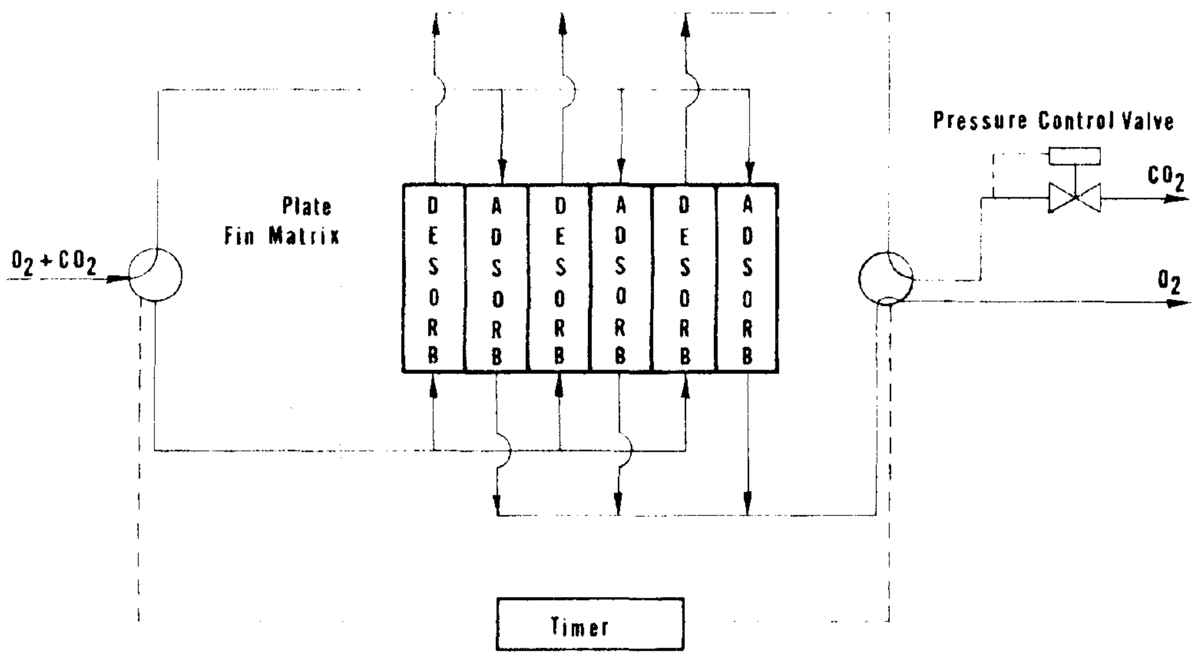
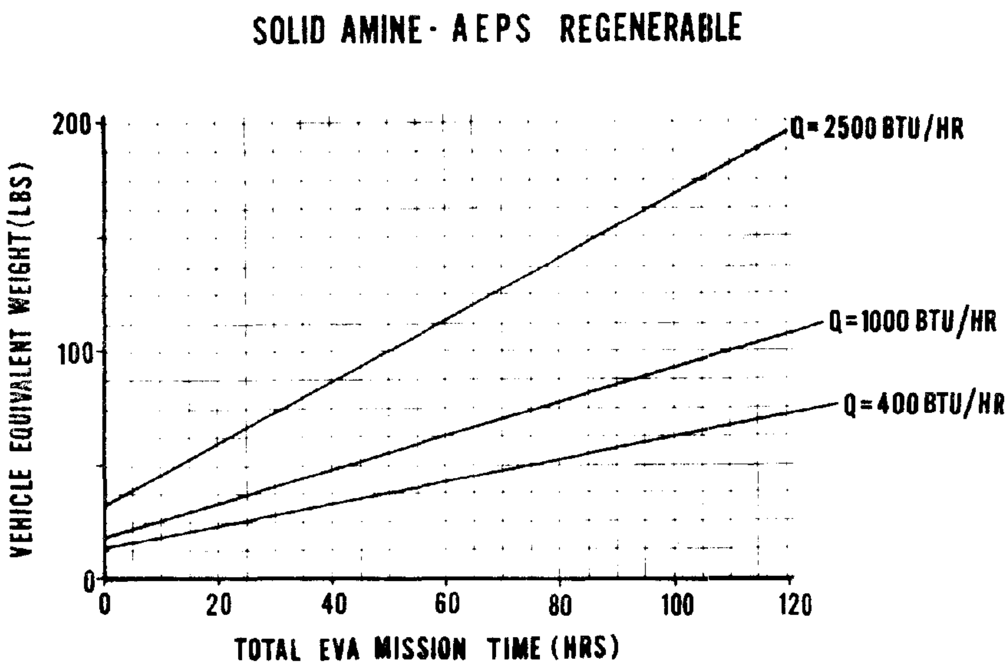
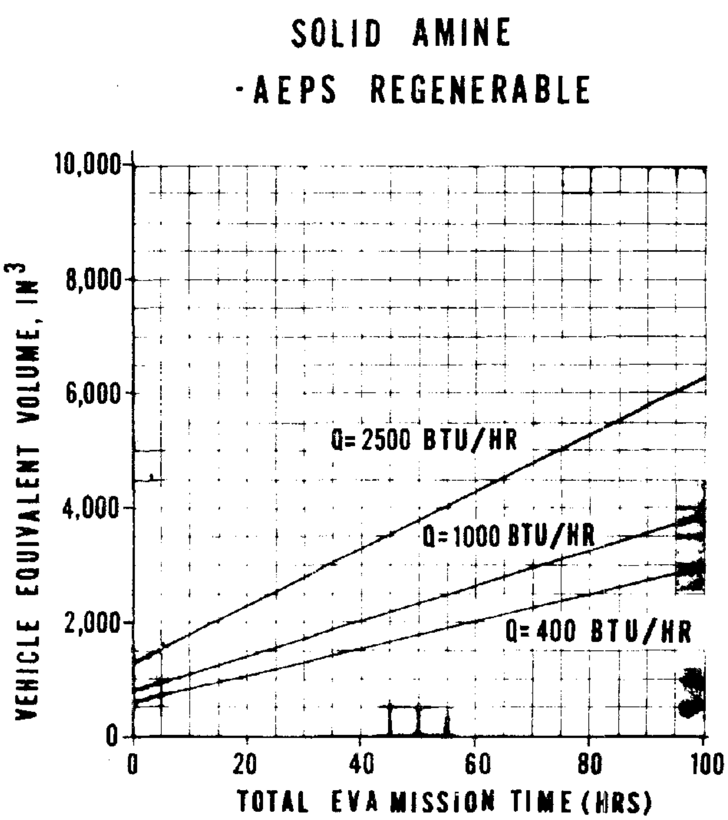
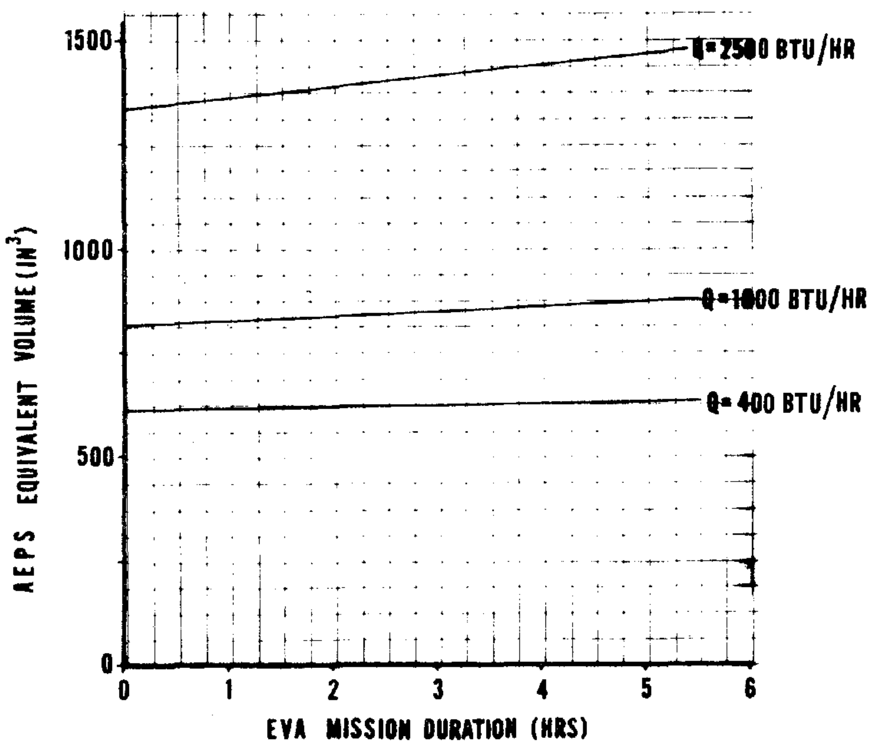


FIGURE 4–47. SOLID AMINE – AEPS REGENERABLE

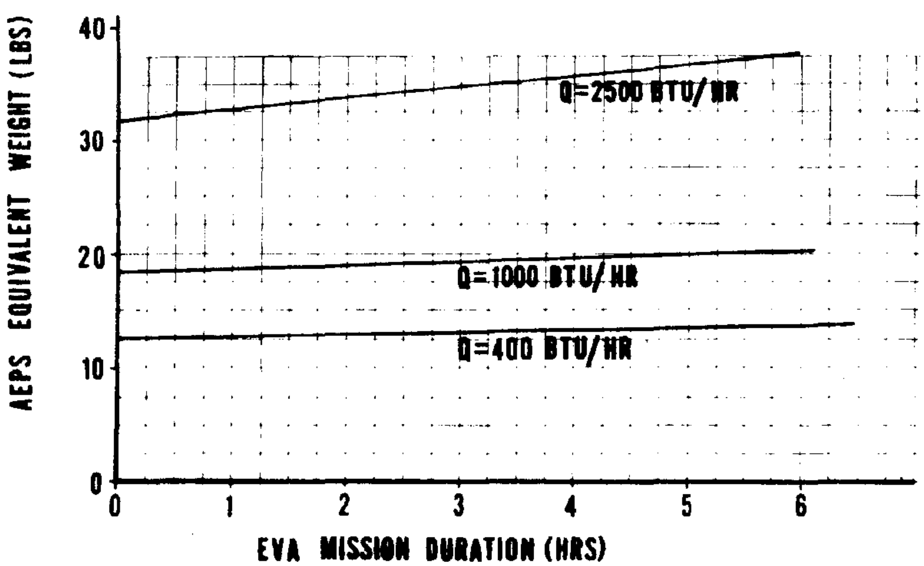

SOLID AMINE- AEPS REGENERABLE
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
VEHICLE EQUIVALENT WEIGHT (LBS)
200
100
0
0
20
40
60
80
100
120
TOTAL EVA MISSION TIME (HRS)


SOLID AMINE
-AEPS REGENERABLE
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
VEHICLE EQUIVALENT VOLUME, IN^3
10,000
8,000
6,000
4,000
2,000
0
0
20
40
60
80
100
TOTAL EVA MISSION TIME (HRS)

SOLID AMINE-AEPS REGENERABLE

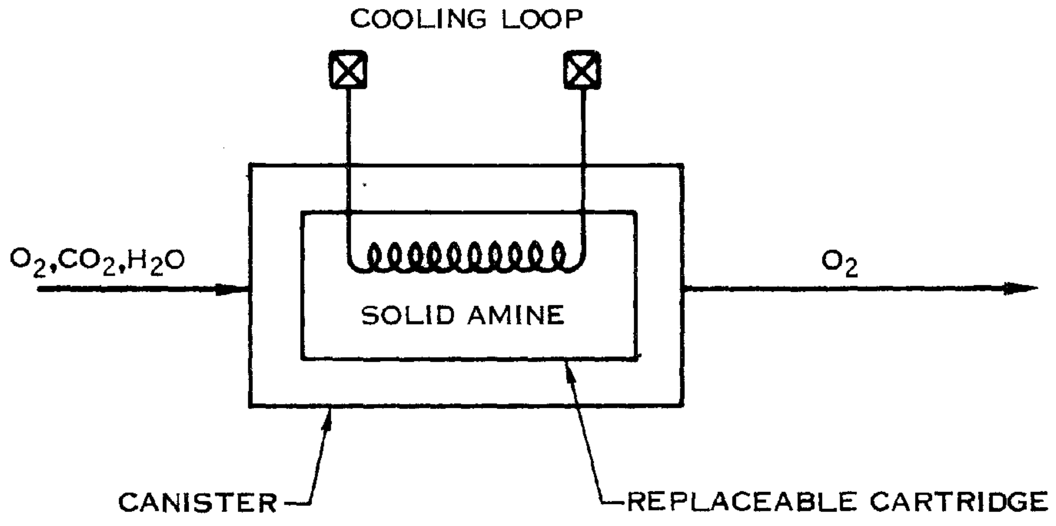


SOLID AMINE-AEPS REGENERABLE

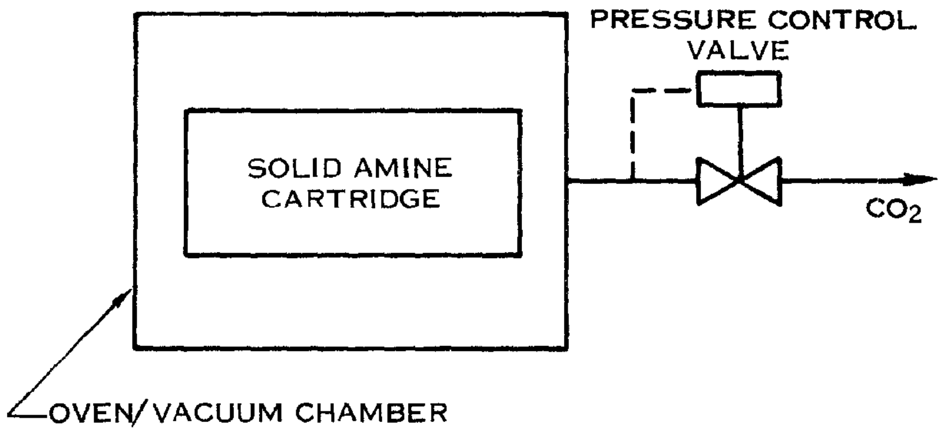


CONEPT 9 - SOLID AMINE - VEHICLE REGENERABLE

A variation of the solid amine concept considers a non-cyclic or vehicle regenerable configuration. The adsorbent is packaged in a water-cooled cartridge which is replaced after each mission. An oven/vacuum chamber is provided within the vehicle for cartridge regeneration. The following curves are based on a 10% CO_2 capacity of the solid amine plus the inert carrier.



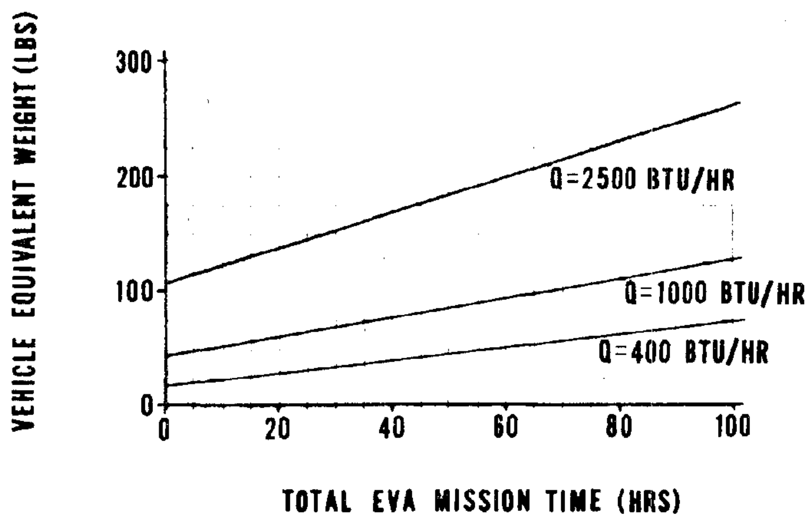
AEPS OPERATION



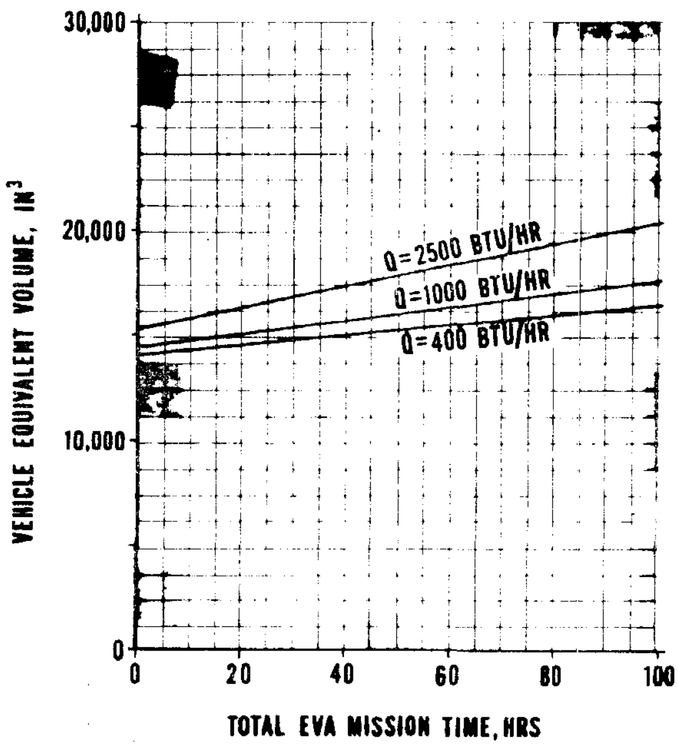
VEHICLE REGENERATION

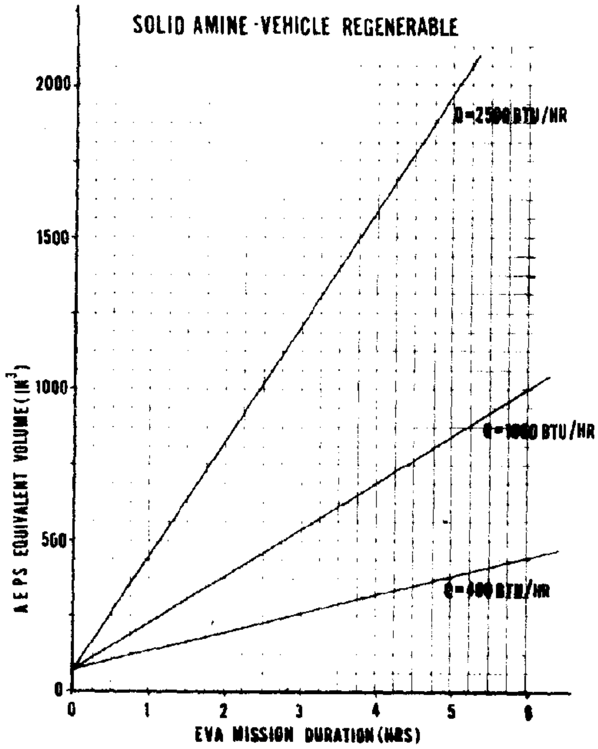
FIGURE 4–48. SOLID AMINE–VEHICLE REGENERABLE

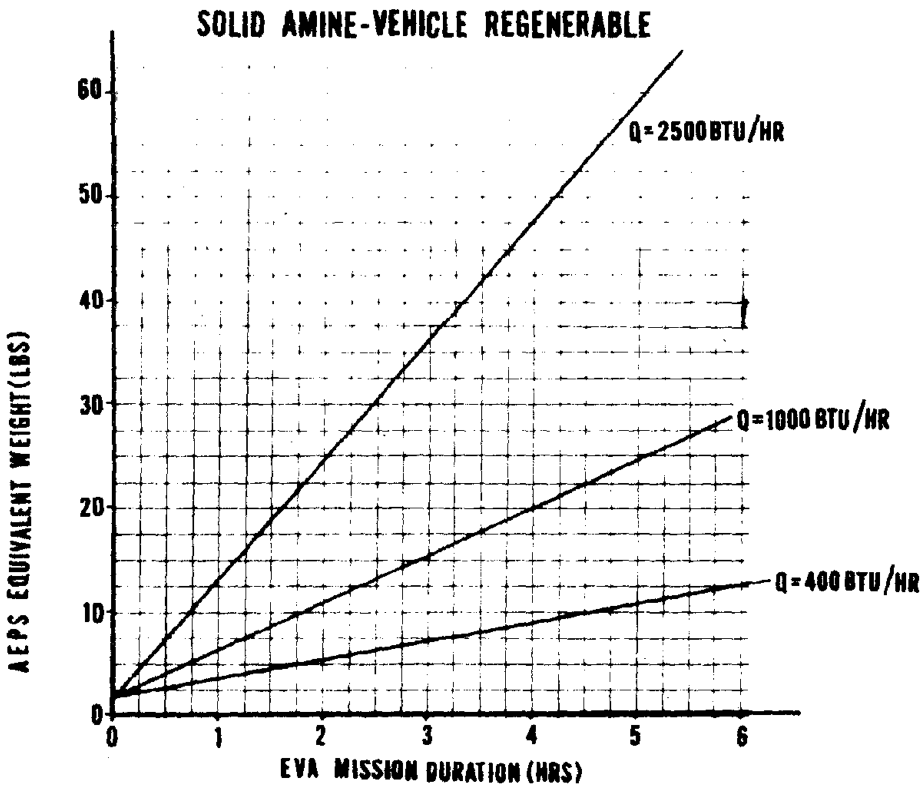
SOLID AMINE – VEHICLE REGENERABLE



SOLID AMINE–VEHICLE REGENERABLE




SOLID AMINE-VEHICLE REGENERABLE
AEPS EQUIVALENT VOLUME (IN³)
0
500
1000
1500
2000
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)


SOLID AMINE-VEHICLE REGENERABLE
AEPS EQUIVALENT WEIGHT (LBS)
0
10
20
30
40
50
60
Q=2500 BTU/HR
Q=1000 BTU/HR
Q=400 BTU/HR
0
1
2
3
4
5
6
EVA MISSION DURATION (HRS)

4.2.2 Emergency Systems Parametric Analyses

For the AEPS Emergency Systems applications, the CO_2 control/O_2 supply subsystem parametric analyses evaluated the candidate concepts for an average metabolic rate of -

Shuttle	1500 BTU/hr
Space Station	1500 BTU/hr
Lunar Base	1600 BTU/hr
Mars	2000 BTU/hr

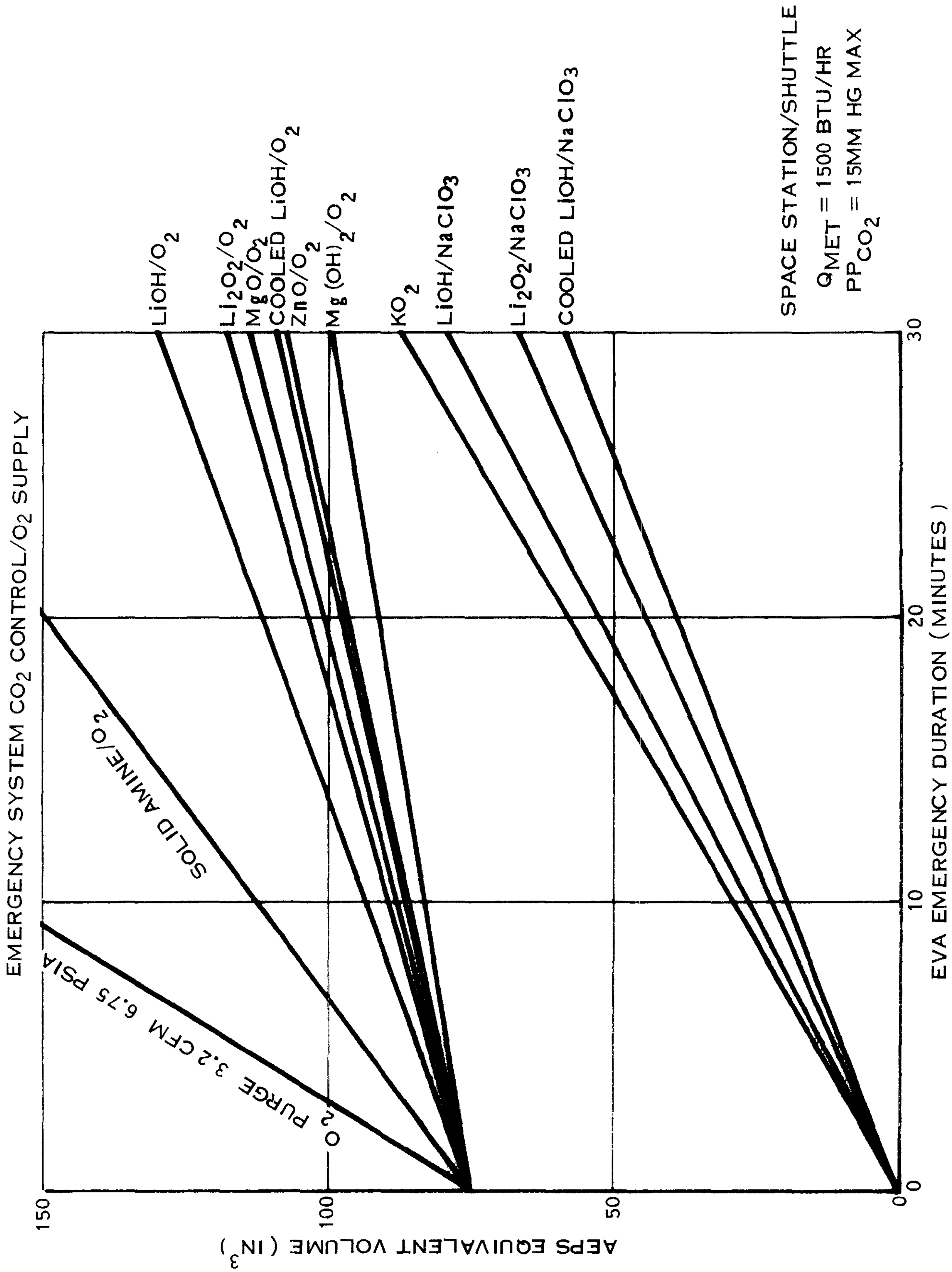
while maintaining the suit inlet CO_2 partial pressure below 15 mm Hg. Unless otherwise specified, the oxygen supply subsystem is a 6000 psi gaseous supply.

The thermal/humidity control subsystem parametric analyses evaluated the candidate concepts for an average thermal load of:

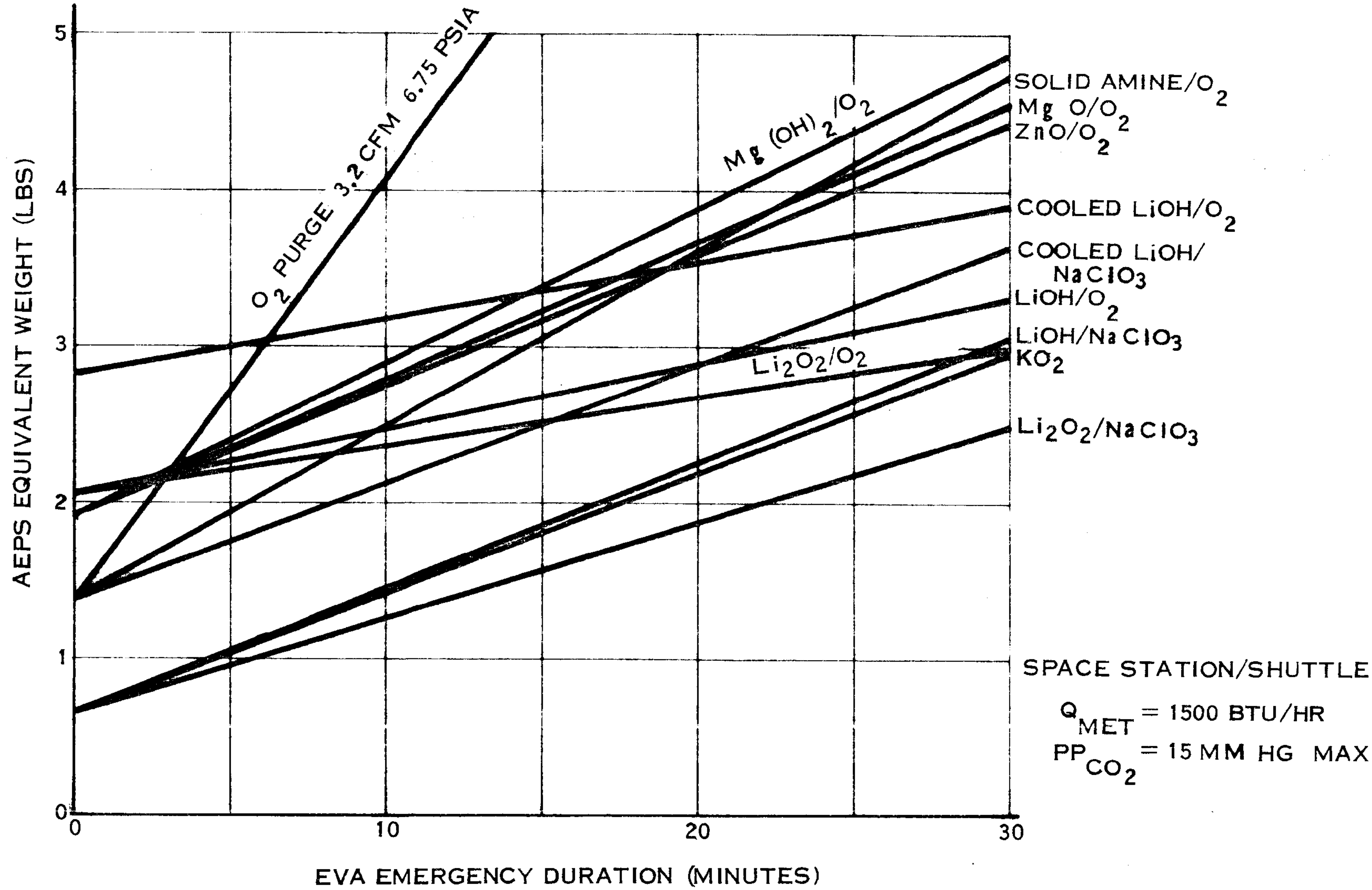
Shuttle	1600 BTU/hr
Space Station	1600 BTU/hr
Lunar Base	2450 BTU/hr
Mars	2200 BTU/hr

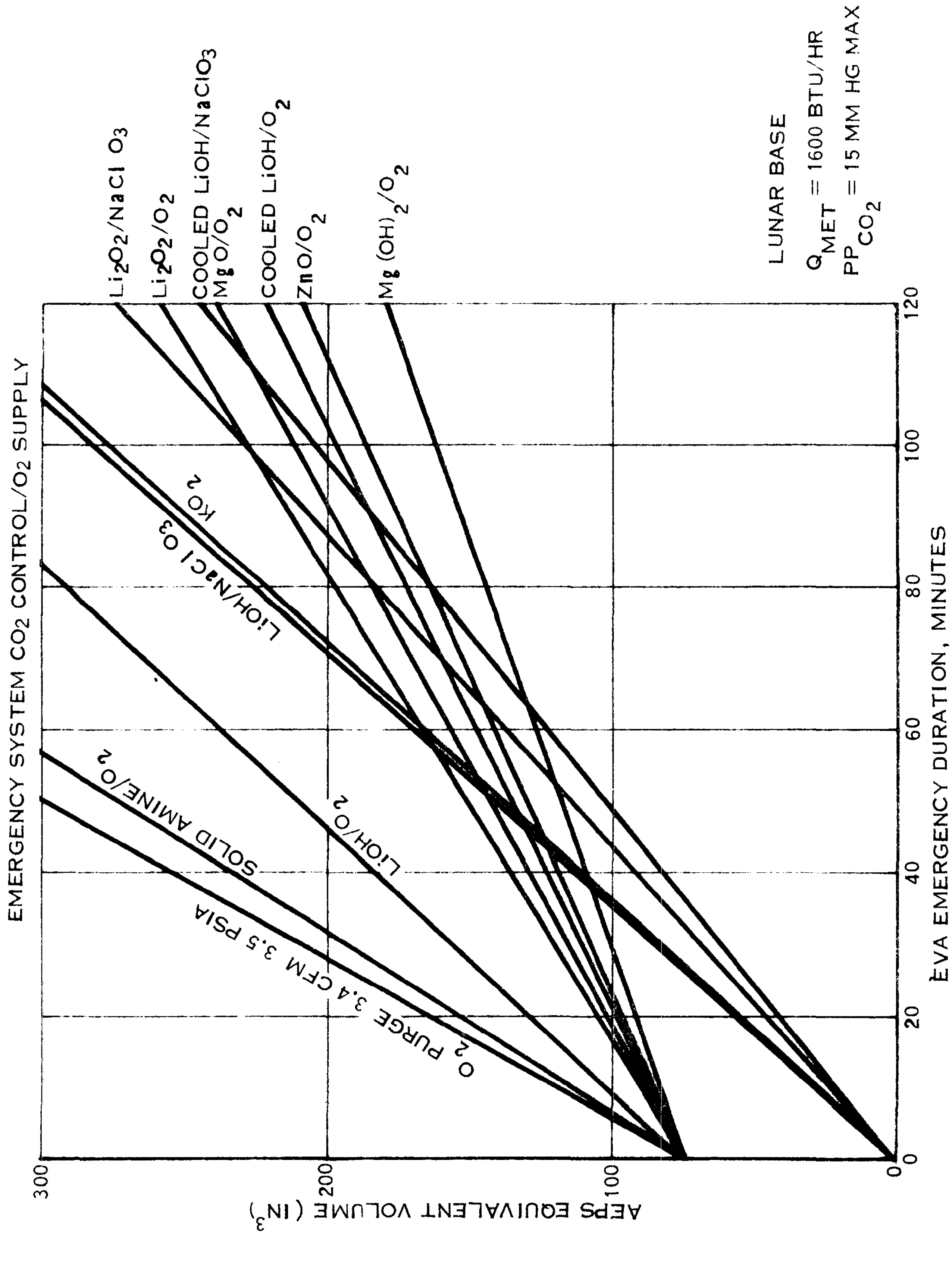
The Emergency Systems parametric analyses are contained on the following pages and are based upon extrapolation of in-house and published test data and a projection of both state-of-the-art and design/development improvements achievable within the time frames specified by this study for each of the emergency systems' respective primary system.

4.2.2.1 CO_2 CONTROL/O_2 SUPPLY


EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY
O_2 PURGE 3.2 CFM 6.75 PSIA
SOLID AMINE/O_2
$LiOH/O_2$
Li_2O_2/O_2
MgO/O_2
COOLED $LiOH/O_2$
ZnO/O_2
$Mg(OH)_2/O_2$
KO_2
$LiOH/NaClO_3$
$Li_2O_2/NaClO_3$
COOLED $LiOH/NaClO_3$
SPACE STATION/SHUTTLE
Q_{MET} = 1500 BTU/HR
PP_{CO_2} = 15MM HG MAX
AEPS EQUIVALENT VOLUME (IN^3)
150
100
50
0
10
20
30
EVA EMERGENCY DURATION (MINUTES)

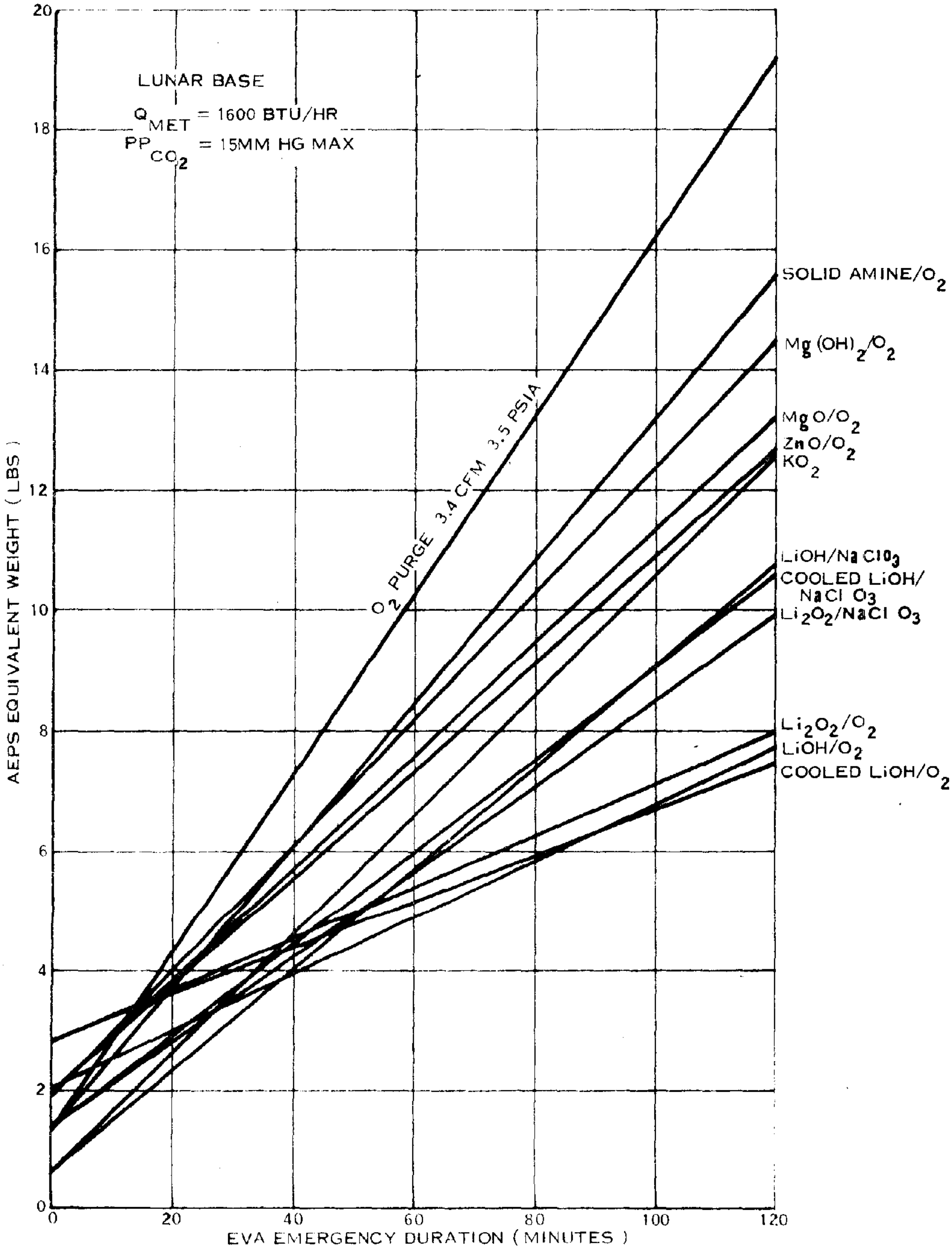
EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY



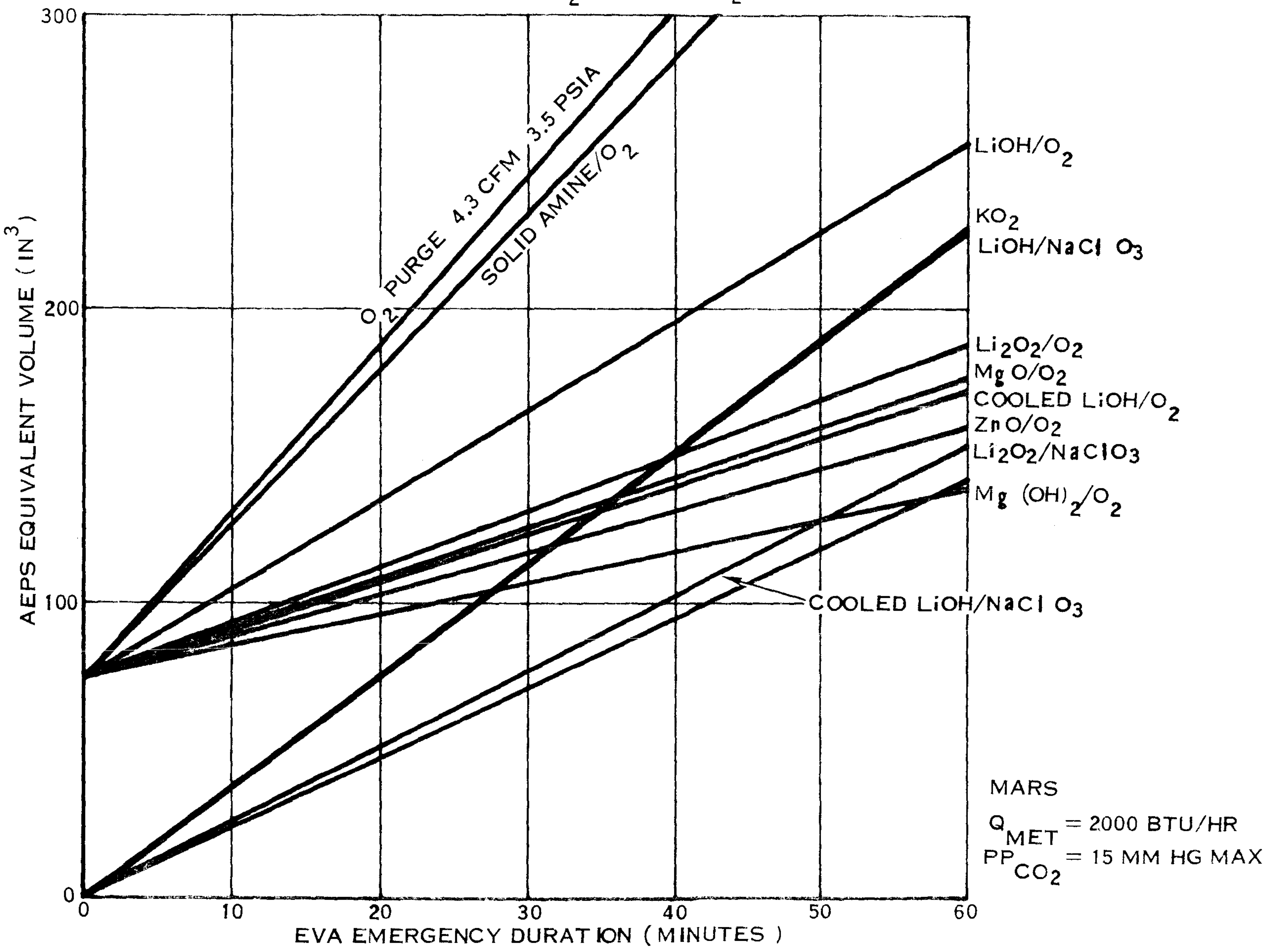


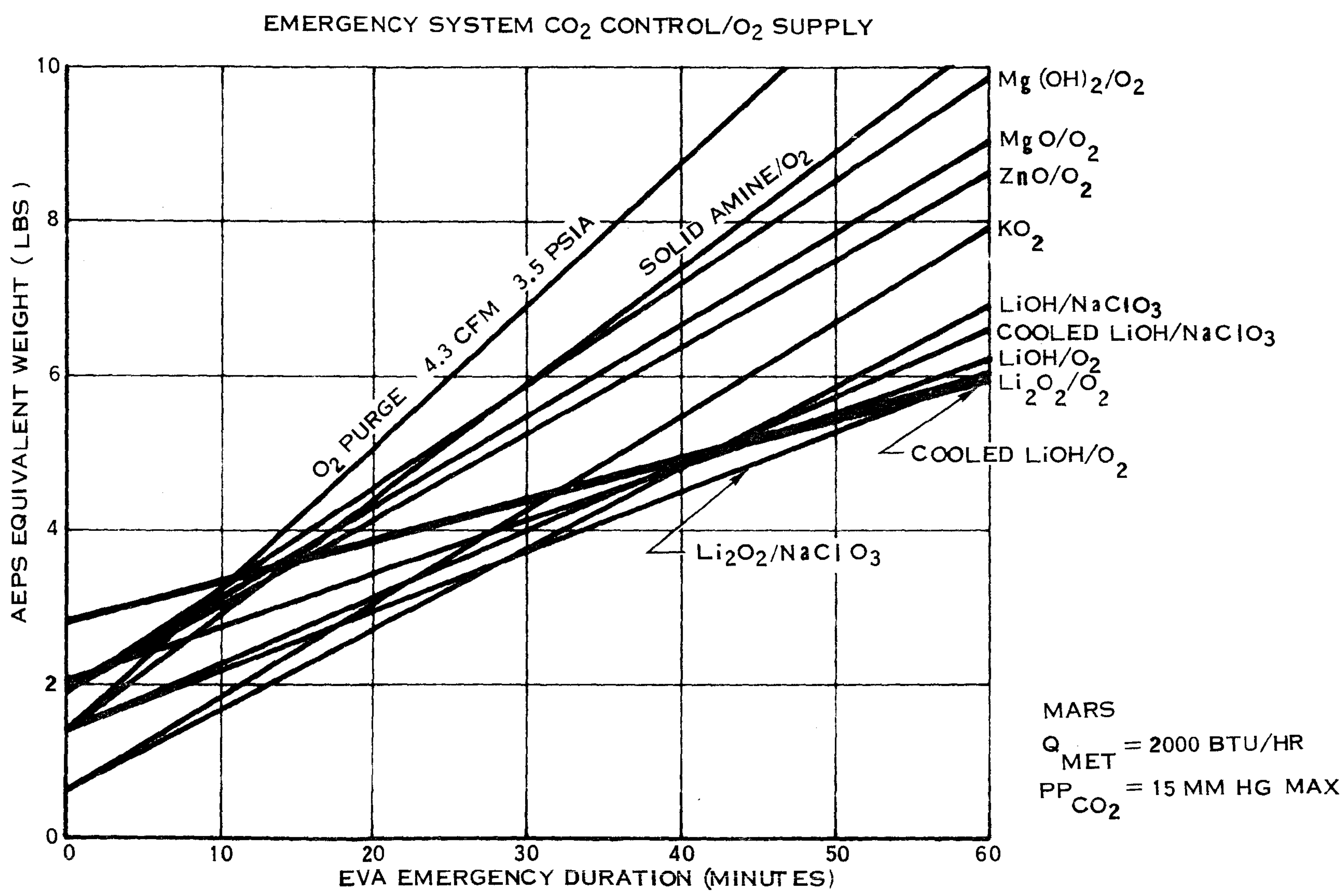
EMERGENCY SYSTEM CO2 CONTROL/O2 SUPPLY
LUNAR BASE
QMET = 1600 BTU/HR
PPCO2 = 15 MM HG MAX
Li2O2/NaCl O3
Li2O2/O2
COOLED LiOH/NaClO3
Mg O/O2
COOLED LiOH/O2
ZnO/O2
Mg (OH)2/O2
KO2
LiOH/NaCl O3
LiOH/O2
SOLID AMINE/O2
O2 PURGE 3.4 CFM 3.5 PSIA
AEPS EQUIVALENT VOLUME (IN3)
EVA EMERGENCY DURATION, MINUTES
0
20
40
60
80
100
120
100
200
300

EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY



EMERGENCY SYSTEM CO_2 CONTROL/O_2 SUPPLY

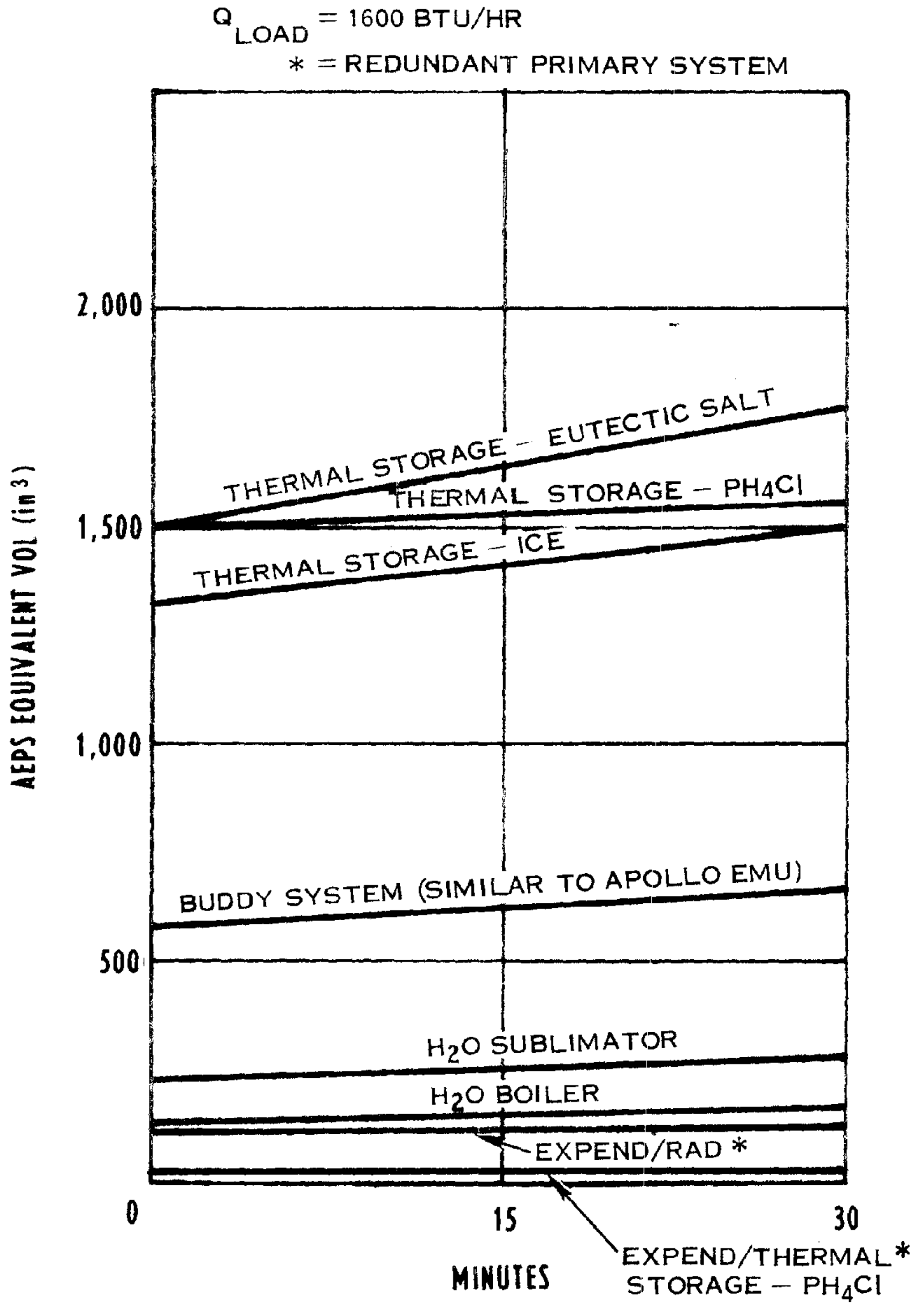



EMERGENCY SYSTEM CO2 CONTROL/O2 SUPPLY
AEPS EQUIVALENT WEIGHT (LBS)
EVA EMERGENCY DURATION (MINUTES)
O2 PURGE 4.3 CFM 3.5 PSIA
SOLID AMINE/O2
Mg (OH)2/O2
Mg O/O2
ZnO/O2
KO2
LiOH/NaClO3
COOLED LiOH/NaClO3
LiOH/O2
Li2O2/O2
COOLED LiOH/O2
Li2O2/NaCl O3
MARS
QMET = 2000 BTU/HR
PPCO2 = 15 MM HG MAX

4.2.2.2 THERMAL/HUMIDITY CONTROL

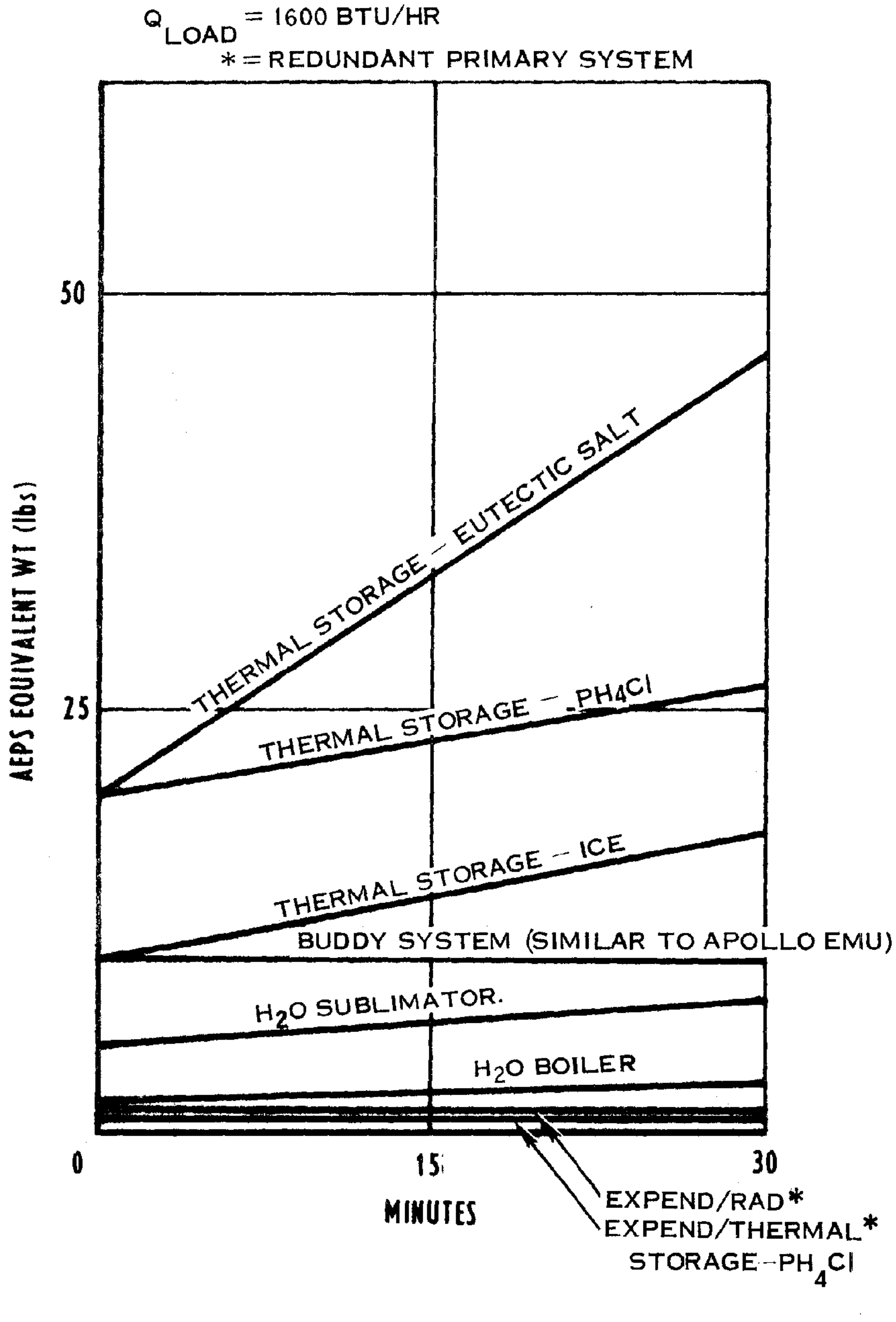
EMERGENCY SYSTEM THERMAL CONTROL

SPACE STATION/SHUTTLE



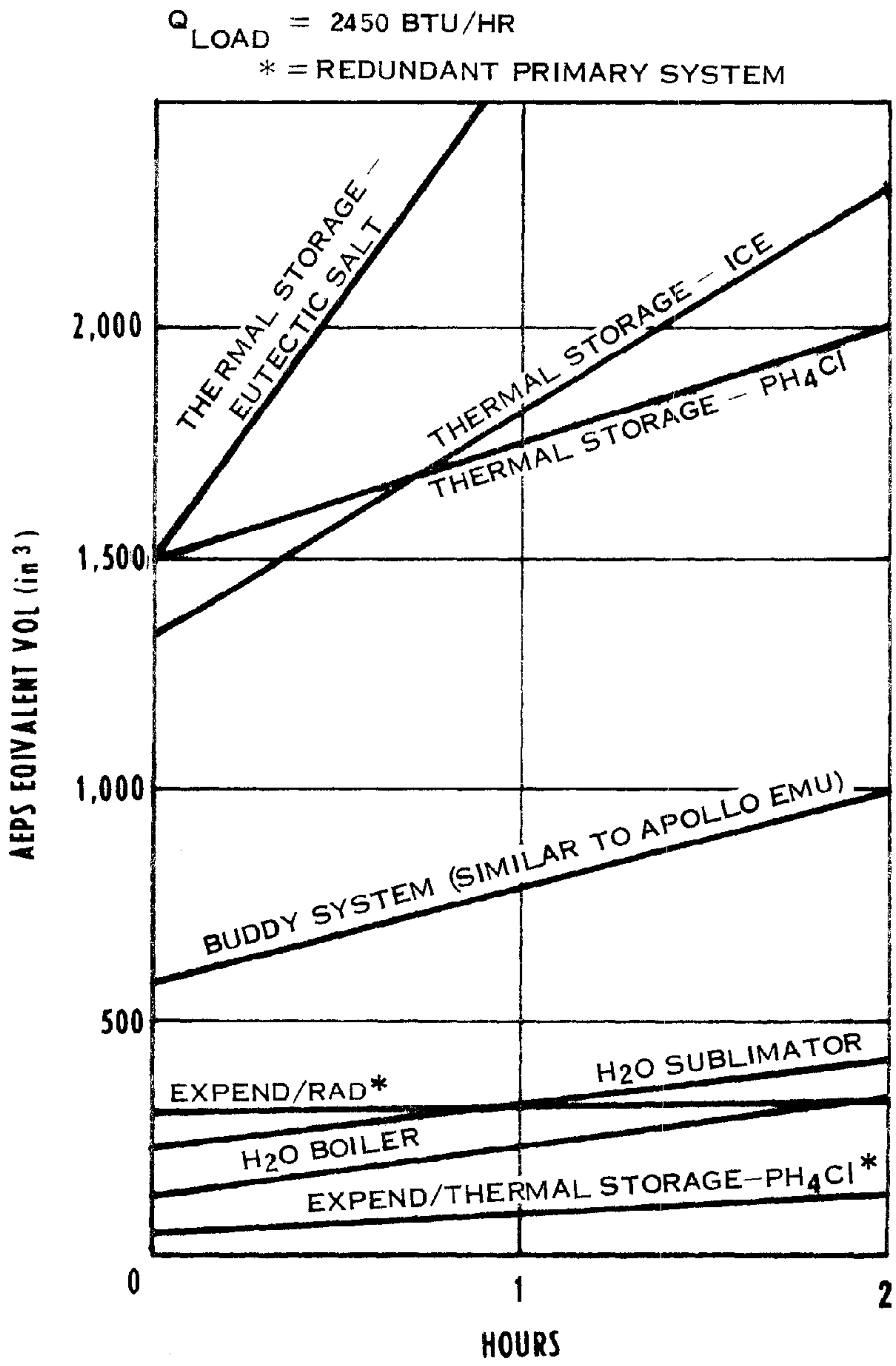
EMERGENCY SYSTEM THERMAL CONTROL

SPACE STATION/SHUTTLE



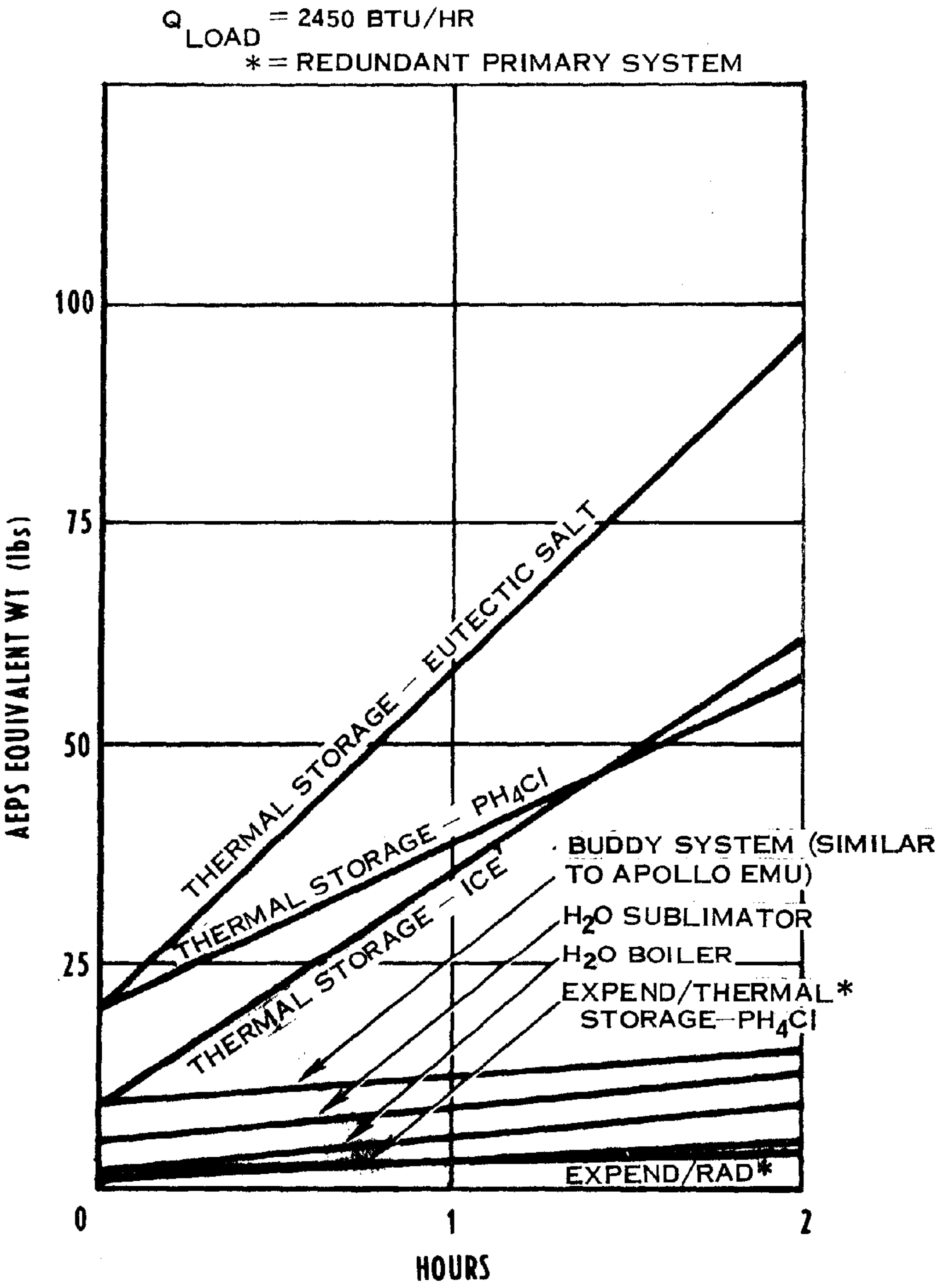
EMERGENCY SYSTEM THERMAL CONTROL

LUNAR BASE



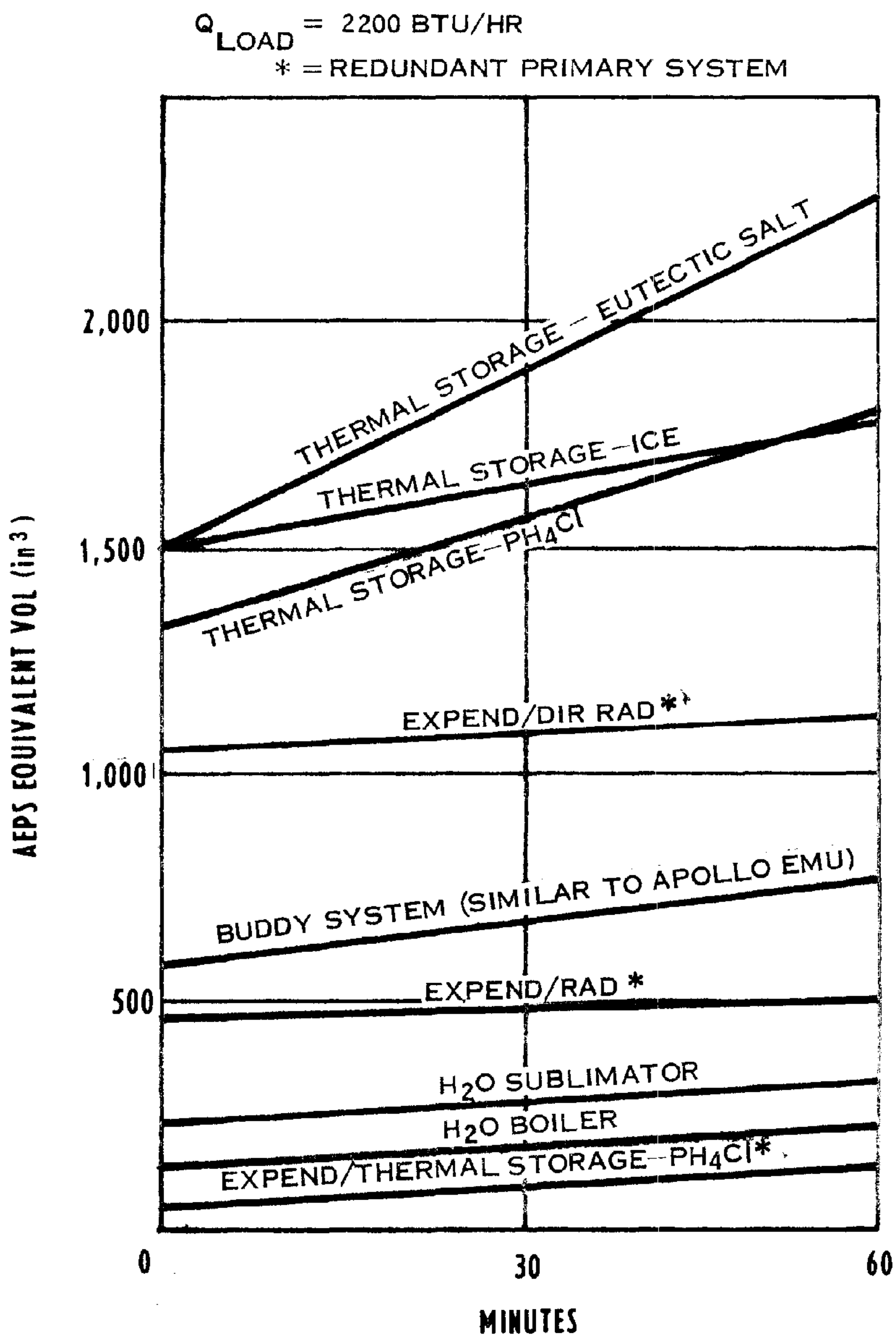
EMERGENCY SYSTEM THERMAL CONTROL

LUNAR BASE



EMERGENCY SYSTEM THERMAL CONTROL

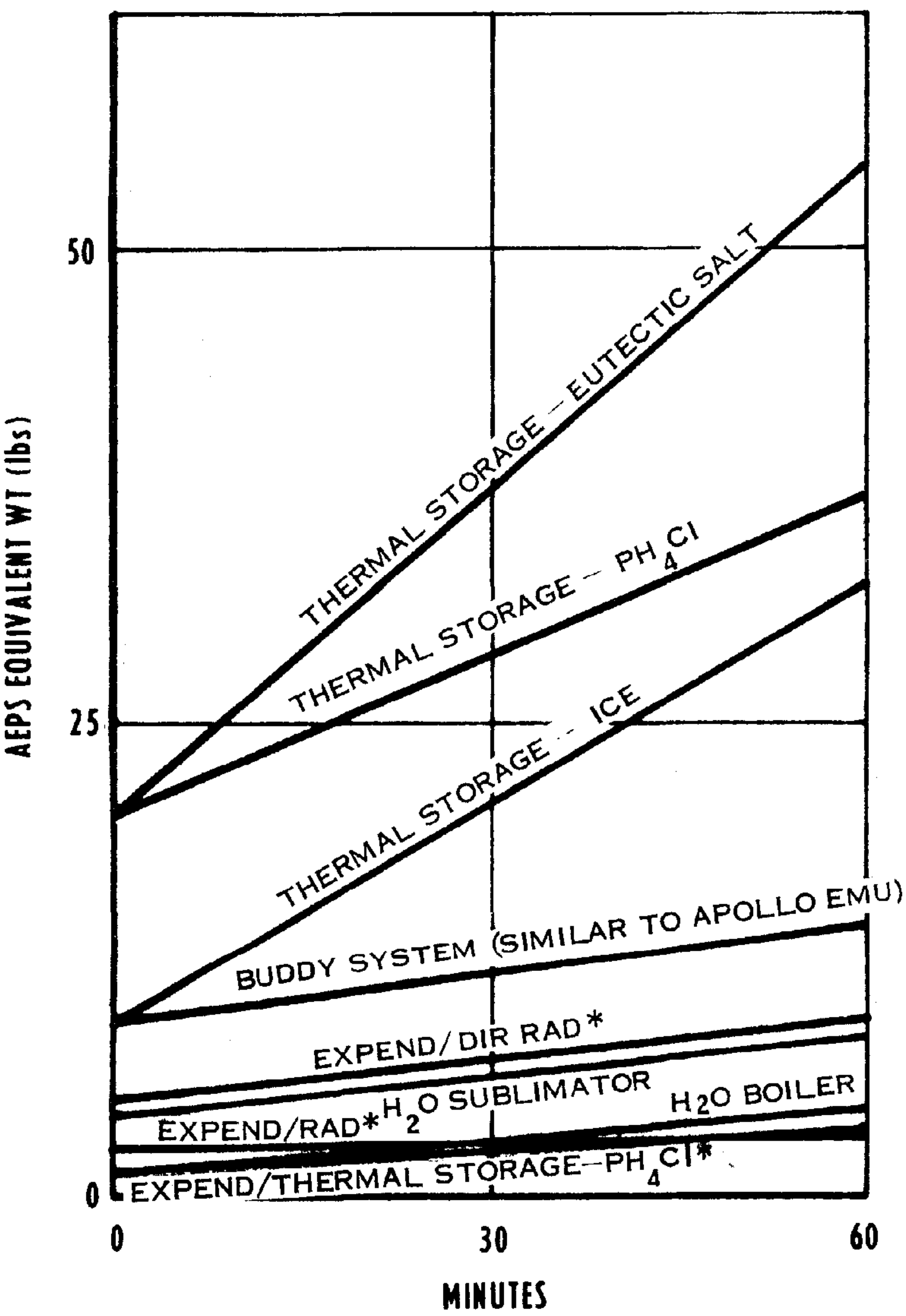
MARS



EMERGENCY SYSTEM THERMAL CONTROL

MARS

Q_{LOAD} = 2200 BTU/HR
* = REDUNDANT PRIMARY SYSTEM



5.0 PRIMARY AND SECONDARY EVALUATIONS

5.0 PRIMARY AND SECONDARY EVALUATIONS

This section describes the primary and secondary evaluations of the candidate thermal control and CO_2 control/O_2 supply subsystem concepts conducted in Phases One & Two of the AEPS study. Implementation of the evaluation criteria is described and the resultant candidate concept ratings are presented.

5.1 Phase One Effort

5.1.1 Primary Evaluation

5.1.1.1 General - All candidate concepts that passed the go/no go evaluation were subjected to the primary evaluation. Each candidate concept received a rating of from 0 to 100 for each primary criterion. The ratings applied to a candidate concept were dependent upon the characteristics of the candidate relative to the other candidates. Each rating was then multiplied by the weighting factors defined in Table 5-1 and the ratings added to obtain a total rating for each candidate concept. A candidate concept was selected if its overall rating was clearly the best of the competing concepts. If a clear-cut choice was not evident, the remaining competing concepts were reviewed against the secondary criteria.

The primary criteria are defined as follows:

Vehicle Equivalent Weight - The physical aspects of any given concept can be converted to an equivalent vehicle launch weight penalty for purposes of comparison. Equivalent vehicle weight consists of subsystem or system fixed weight, expendables, power requirements, heat rejection requirements, recharge and/or regeneration equipment, spares, and special interface equipment. If the equivalent vehicle weight for a given concept is greater than that for the existing Apollo EMU concept, it is eliminated.

AEPS Equivalent Volume - EVA equipment volume consists of all EVA life support equipment with which the crewman must egress from the vehicle and is an indirect measurement of crewman encumbrance and mobility hindrance. This criterion, as is equivalent vehicle weight, is a tool that provides an objective quantitative basis for evaluation and represents the two most important evaluating criteria for use during the study.

Reliability - Reliability is a measure of the probability that a concept will meet the total mission requirements with a minimum of spares, redundancy and maintenance time. In addition, single point failures and sequential failures are eliminated. Application of these criteria entail objective engineering assessments and do not involve interpolation of numbers representing failure probability estimates.

Operability - Operability is a measure of the concept's ability to be simply used for the mission's various operating modes including: don/doff, startup, checkout, egress/ingress, shutdown, recharge/regeneration, and operational variations during the actual EVA. If the operability of a candidate concept is considered unacceptable, it is eliminated.

5.1.1.1 (continued)

Flexibility - Flexibility is a measure of the concept's ability to be used under various conditions at minimum penalty:

a. Different types of EVA missions such as exploration, cargo transfer, assembly operations, etc.
b. Different space programs involving varying gravity environments, thermal environments, etc.
c. Adaptability of incorporating new technology, thus preventing premature technical obsolescence.

TABLE 5-1 PRIMARY CRITERIA WEIGHTING FACTORS

Criteria	Weighting Factors		
	Space Station	Lunar Base	Mars Landing
Vehicle Equivalent Weight	0.30	0.35	0.35
AEPS Equivalent Volume	0.30	0.25	0.25
Reliability	0.15	0.15	0.15
Operability	0.15	0.15	0.15
Flexibility	0.10	0.10	0.10

The primary criteria whose ratings were determined quantitatively are vehicle equivalent weight and AEPS equivalent volume. The competitive ratings for both these criteria were determined by establishing a straight-line relationship between the criteria rating and vehicle equivalent weight or AEPS equivalent volume, as the case may be, on a semi-log scale. The relationships were established for both thermal control and CO_2 control/O_2 supply concepts, on a mission basis, by selecting criteria values that corresponded with a 100 point criteria rating and a 10 point criteria rating in accordance with Table 5-2.

The criteria ratings for the candidate subsystem concepts were then simply determined by selecting the rating corresponding to the concept's vehicle equivalent weight or AEPS equivalent volume as defined by the parametric analysis presented in Section 4.0. A semi-log scale was utilized to provide added benefit to those concepts that exhibited low vehicle weights and AEPS equivalent volumes and to penalize those concepts with high vehicle equivalent weights and AEPS equivalent volumes.

QUANTITATIVE PRIMARY CRITERIA RATING END POINTS

SUBSYSTEM	PRIMARY CRITERION	MISSION		
		SPACE STATION	LUNAR BASE	MARS
Thermal Control	Vehicle Equivalent Weight 100 points 10 points	 0 1500 lbs	 0 3300 lbs	 0 3300 lbs
	AEPS Equivalent Volume 100 points 10 points	 500 in^3 2650 in^3	 800 in^3 5000 in^3	 800 in^3 5000 in^3
CO_2 Control/O_2 Supply	Vehicle Equivalent Weight 100 points 10 points	 300 lbs 1100 lbs	 600 lbs 2200 lbs	 600 lbs 2200 lbs
	AEPS Equivalent Volume 100 points 10 points	 250 in^3 2500 in^3	 400 in^3 5000 in^3	 400 in^3 5000 in^3

TABLE 5-2

5.1.1.1 (continued)

The ratings of the three remaining primary criteria were determined qualitatively. The reliability rating was a comparative assessment of candidate concepts and was based upon the total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

The operability rating was determined by dividing operability into seven subareas and weighting each area as follows:

A.	Don/doff	15 points
B.	Startup	5
C.	Checkout	15
D.	Egress/ingress	10
E.	Shutdown	5
F.	Recharge/regeneration	25
G.	Operational variations during EVA	25
		100 points

A relative assessment of each candidate concept was then made and the sum of the ratings of the seven subareas was equal to the total operability rating for each candidate concept.

The flexibility rating was determined by dividing flexibility into three subareas and weighting each area as follows:

A.	EVA mission flexibility	50 points
B.	Applicability to different space programs	25
C.	Ability to incorporate new technology	25
		100 points

A relative assessment of each candidate concept was then made and the sum of the ratings of the three subareas was equal to the total flexibility rating for each candidate concept.

The rating for each primary criterion was multiplied by the weighting factors defined in Table 5-1 and then summed up to determine the final competitive rating for each candidate concept.

5.1.1.2 Thermal Control - Table 5-3 is an index of the eighteen (18) candidate thermal control concepts that passed the go/no go evaluation and were carried into the primary evaluation. Concepts 1-5, 9-11, 13-15 and 18 were considered for Space Station, all eighteen were considered for Lunar Base, and all but concept 2 were considered for Mars.

TABLE 5-3

THERMAL CONTROL CONCEPT INDEX

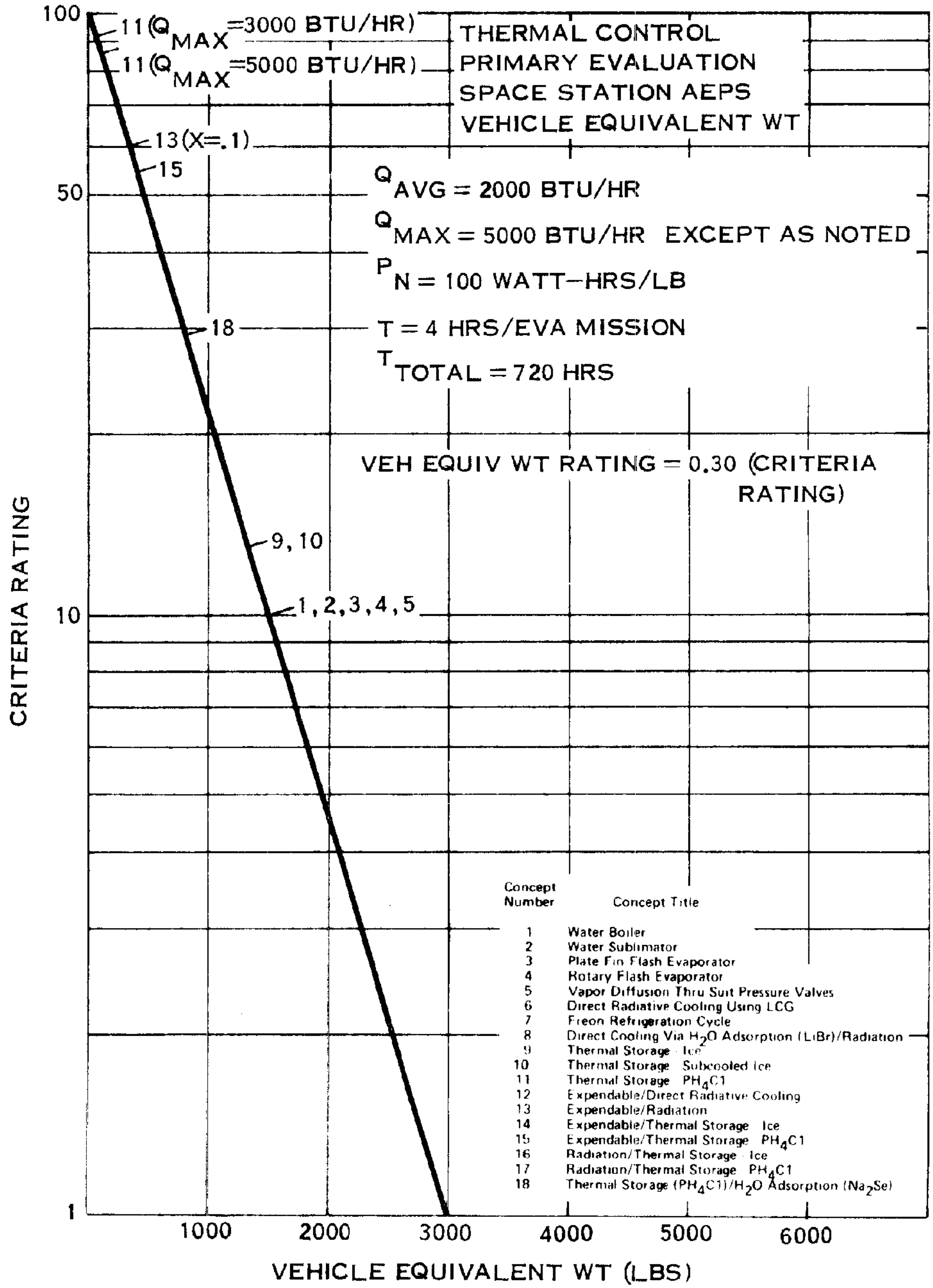
Concept Number	Concept Title
1	Water Boiler
2	Water Sublimator
3	Plate Fin Flash Evaporator
4	Rotary Flash Evaporator
5	Vapor Diffusion Thru Suit Pressure Valves
6	Direct Radiative Cooling Using LCG
7	Freon Refrigeration Cycle
8	Direct Cooling Via H_2O Adsorption (LiBr)/Radiation
9	Thermal Storage - Ice
10	Thermal Storage - Subcooled Ice
11	Thermal Storage - PH_4Cl
12	Expendable/Direct Radiative Cooling
13	Expendable/Radiation
14	Expendable/Thermal Storage - Ice
15	Expendable/Thermal Storage - PH_4Cl
16	Radiation/Thermal Storage - Ice
17	Radiation/Thermal Storage - PH_4Cl
18	Thermal Storage (PH_4Cl)/H_2O Adsorption (Na_2Se)

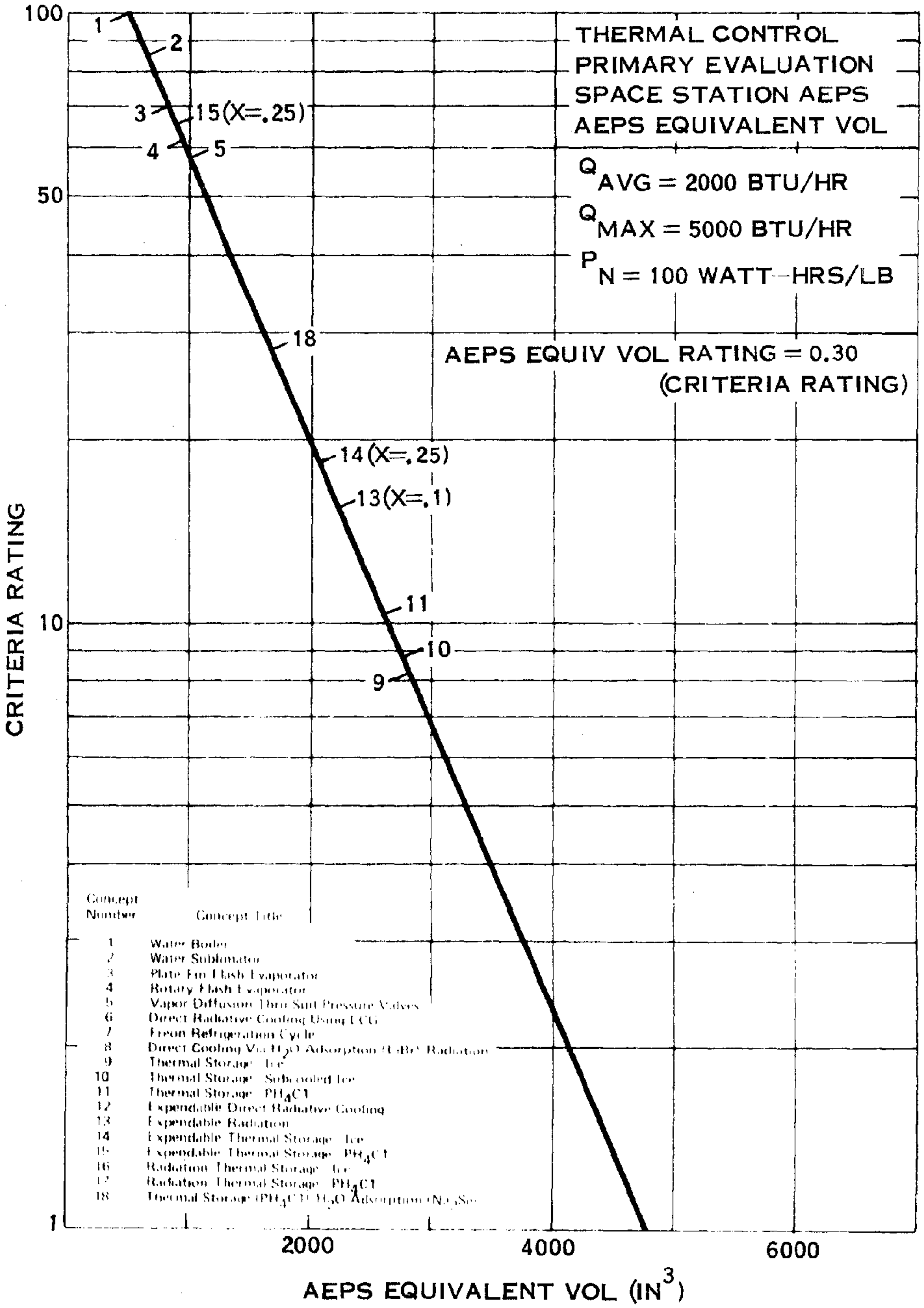
The following nine (9) concepts passed the primary evaluation and were carried into the secondary evaluation:

a. Water Boiler
b. Water Sublimator
c. Direct Radiative Cooling Using LCG
d. Freon Refrigeration Cycle
e. Thermal Storage - PH_4Cl
f. Expendable/Direct Radiative Cooling
g. Expendable/Radiation
h. Expendable/Thermal Storage - PH_4Cl
i. Radiation/Thermal Storage - PH_4Cl

Implementation of the primary evaluation criteria and the resultant candidate thermal control concept ratings are presented in detail on the following pages.

SPACE STATION


THERMAL CONTROL
PRIMARY EVALUATION
SPACE STATION AEPS
VEHICLE EQUIVALENT WT
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR EXCEPT AS NOTED
P_N = 100 WATT–HRS/LB
T = 4 HRS/EVA MISSION
T_{TOTAL} = 720 HRS
VEH EQUIV WT RATING = 0.30 (CRITERIA RATING)
11 (Q_{MAX}=3000 BTU/HR)
11 (Q_{MAX}=5000 BTU/HR)
13 (X=.1)
15
18
9, 10
1, 2, 3, 4, 5
CRITERIA RATING
100
50
10
1
1000
2000
3000
4000
5000
6000
VEHICLE EQUIVALENT WT (LBS)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr)/Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage Ice
15 Expendable/Thermal Storage PH_4C1
16 Radiation/Thermal Storage Ice
17 Radiation/Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1)/H_2O Adsorption (Na_2Se)



THERMAL CONTROL
PRIMARY EVALUATION
SPACE STATION AEPS
AEPS EQUIVALENT VOL
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT-HRS/LB
AEPS EQUIV VOL RATING = 0.30
(CRITERIA RATING)
CRITERIA RATING
100
50
10
1
AEPS EQUIVALENT VOL (IN^3)
2000
4000
6000
1
2
3
15(X=.25)
4
5
18
14(X=.25)
13(X=.1)
11
10
9
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable Direct Radiative Cooling
13 Expendable Radiation
14 Expendable Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2S)

THERMAL CONTROL
PRIMARY EVALUATION - SPACE STATION AEPS

RELIABILITY

Concept	Rating
1	13.6
2	15.0
3	11.0
4	10.0
5	1.8
9	13.6
10	6.8
11	11.0
13	13.4
14	11.7
15	10.0
18	10.0

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

THERMAL CONTROL
PRIMARY EVALUATION - SPACE STATION AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	4	14	10	5	25	25	98	15
2	15	4	14	10	4	25	25	97	14.9
3	15	4	12	10	4	25	25	95	14.6
4	15	4	11	10	4	25	25	94	14.4
5	7	4	3	10	5	20	25	74	11.3
9	13	3.5	10	2	3	7	15	53.5	8.2
10	14	1	7	2	1	0	15	40	6.1
11	14	5	13	2	5	25	20	84	12.9
13	5	4	12	2	5	25	20	73	11.2
14	14	3	8	2	3	5	20	55	8.4
15	15	4	12	10	5	25	20	91	13.9
18	14.5	1	7	5	1	5	20	53.5	8.2

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

Operability Rating = $\frac{\text{total}}{100}$ (15) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

THERMAL CONTROL
PRIMARY EVALUATION - SPACE STATION AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	16	0	66	6.6
3	50	25	10	85	8.5
4	50	25	10	85	8.5
5	50	25	10	85	8.5
9	30	25	0	55	5.5
10	20	25	0	45	4.5
11	40	25	25	90	9.0
13	45	20	20	85	8.5
14	40	25	0	65	6.5
15	50	25	25	100	10.0
18	40	25	25	90	9.0

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100}\ (10)\ \text{(Normalizing Factor)*}$$

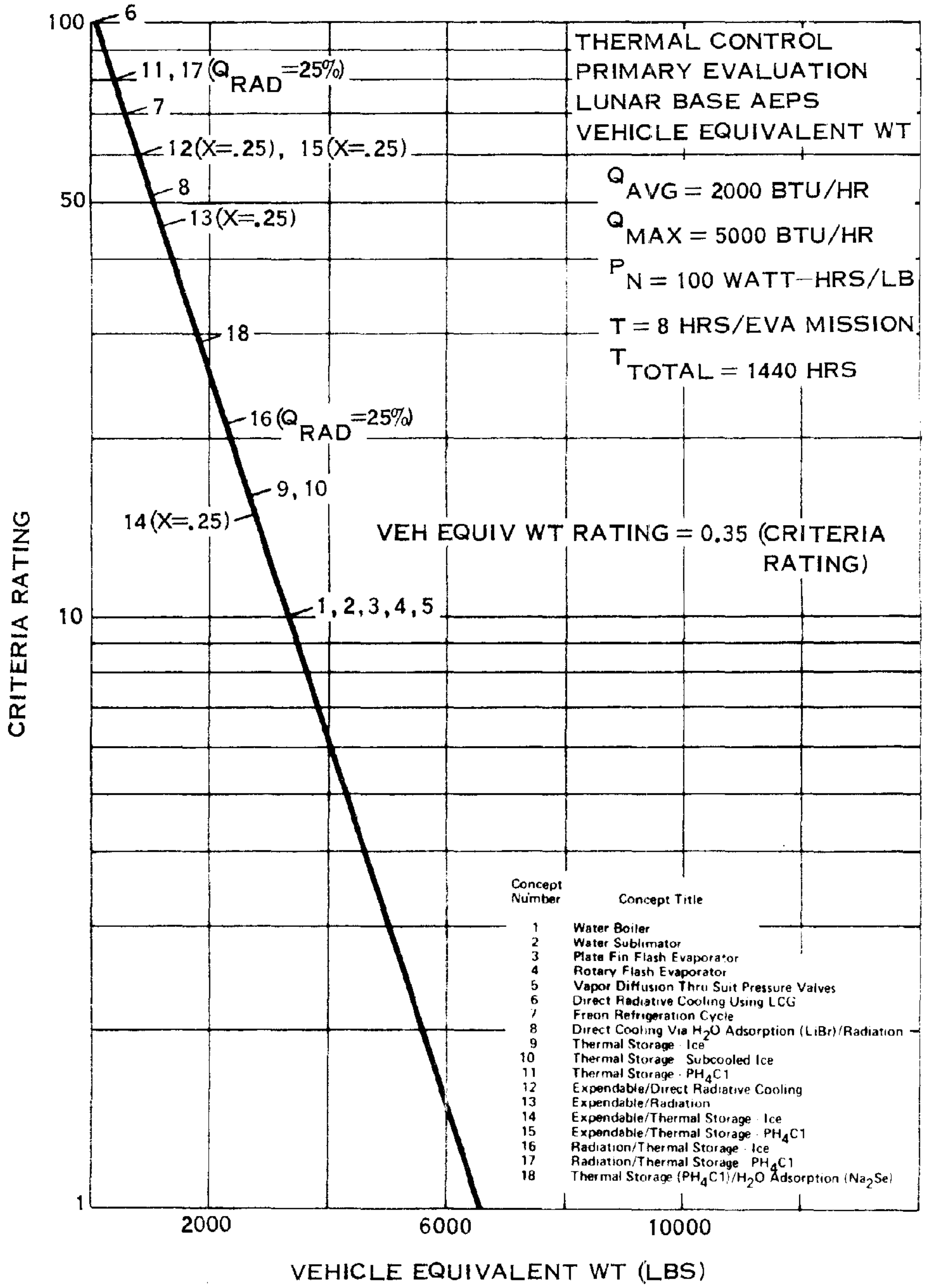
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

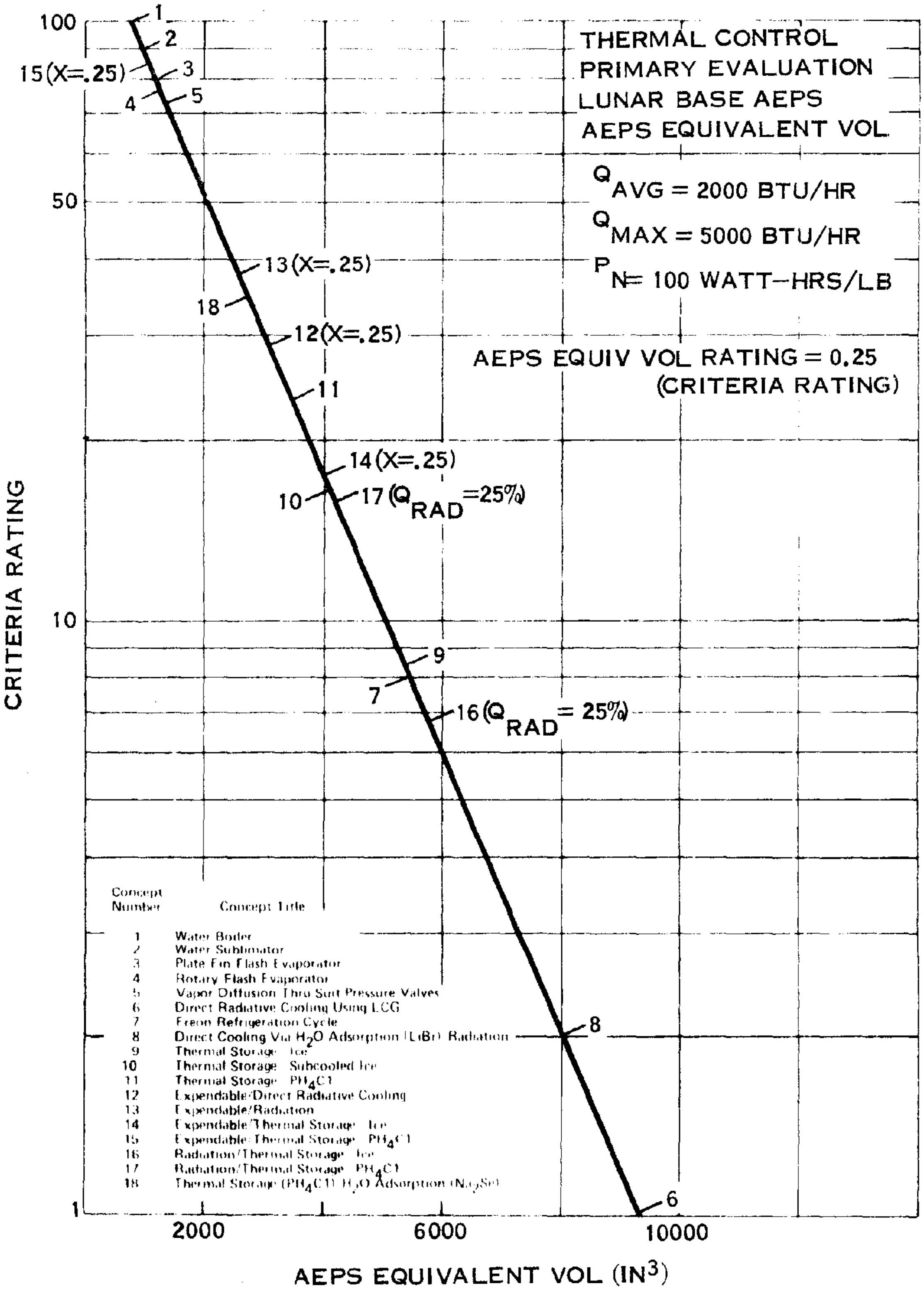
THERMAL CONTROL
PRIMARY EVALUATION - SPACE STATION AEPS

SUMMARY

Concept	AEPS Vol.	Veh. Wt.	Reliability	Operability	Flexibility	Total
	Criteria					
1	30.0	10.0	13.6	15.0	7.5	72.5
2	24.6	10.0	15.0	14.9	6.6	66.6
3	18.9	10.0	11.0	14.6	8.5	59.4
4	18.0	10.0	10.0	14.4	8.5	57.3
5	16.8	10.0	1.8	11.3	8.5	44.8
9	2.3	4.1	13.6	8.2	5.5	33.7
10	2.6	4.1	6.8	6.1	4.5	24.1
11	3.8	27.0	11.0	12.9	9.0	63.7
13	4.4	18.0	13.4	11.2	8.5	55.5
14	5.0	1.1	11.7	8.4	6.5	32.7
15	21.0	16.5	10.0	13.9	10.0	71.4
18	8.1	8.7	10.0	8.2	9.0	54.0

LUNAR BASE


THERMAL CONTROL
PRIMARY EVALUATION
LUNAR BASE AEPS
VEHICLE EQUIVALENT WT
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
T = 8 HRS/EVA MISSION
T_{TOTAL} = 1440 HRS
VEH EQUIV WT RATING = 0.35 (CRITERIA RATING)
CRITERIA RATING
100
50
10
1
2000
6000
10000
VEHICLE EQUIVALENT WT (LBS)
6
11, 17 (Q_{RAD}=25%)
7
12(X=.25), 15(X=.25)
8
13(X=.25)
18
16(Q_{RAD}=25%)
9, 10
14(X=.25)
1, 2, 3, 4, 5
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr)/Radiation
9 Thermal Storage - Ice
10 Thermal Storage - Subcooled Ice
11 Thermal Storage - PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage - Ice
15 Expendable/Thermal Storage - PH_4C1
16 Radiation/Thermal Storage - Ice
17 Radiation/Thermal Storage - PH_4C1
18 Thermal Storage (PH_4C1)/H_2O Adsorption (Na_2Se)


THERMAL CONTROL
PRIMARY EVALUATION
LUNAR BASE AEPS
AEPS EQUIVALENT VOL
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
AEPS EQUIV VOL RATING = 0.25
(CRITERIA RATING)
CRITERIA RATING
100
50
10
1
2000
6000
10000
AEPS EQUIVALENT VOL (IN^3)
1
2
15(X=.25)
3
4
5
13(X=.25)
18
12(X=.25)
11
14(X=.25)
10
17 (Q_{RAD}=25%)
9
7
16 (Q_{RAD} = 25%)
8
6
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4Cl
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage Ice
15 Expendable/Thermal Storage PH_4Cl
16 Radiation/Thermal Storage Ice
17 Radiation/Thermal Storage PH_4Cl
18 Thermal Storage (PH_4Cl) H_2O Adsorption (Na_2Se)

THERMAL CONTROL
PRIMARY EVALUATION - LUNAR BASE AEPS

RELIABILITY

Concept	Rating
1	12.6
2	13.9
3	10.2
4	9.3
5	1.7
6	13.9
7	13.2
8	10.9
9	12.6
10	6.3
11	10.2
12	15.0
13	12.4
14	10.8
15	9.3
16	11.9
17	9.3
18	9.3

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

THERMAL CONTROL
PRIMARY EVALUATION - LUNAR BASE AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	4	14	10	5	25	25	98	15
2	15	4	14	10	4	25	25	97	14.9
3	15	4	12	10	4	25	25	95	14.6
4	15	4	11	10	4	25	25	94	14.4
5	7	4	3	10	5	20	25	74	11.3
6	5	5	15	1	5	25	15	71	10.9
7	5	5	14	1	5	23	15	68	10.4
8	5	1	8	1	1	5	15	36	5.5
9	13	3.5	10	2	3	7	15	53.5	8.2
10	14	1	7	2	1	0	15	40	6.1
11	14	5	13	2	5	25	20	84	12.9
12	5	4	14	1	5	25	15	69	10.6
13	5	4	12	1	5	25	15	67	10.3
14	14	3	8	2	3	5	20	55	8.4
15	15	4	12	10	5	25	20	91	13.9
16	5	3.5	9	1	3	7	15	43.5	6.7
17	5	5	13	1	5	25	15	69	10.6
18	14.5	1	7	5	1	5	20	53.5	8.2

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

$$\text{Operability Rating} = \frac{\text{total}}{100}\ (15)\ \ (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

THERMAL CONTROL
PRIMARY EVALUATION - LUNAR BASE AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	16	0	66	6.6
3	50	25	10	85	8.5
4	50	25	10	85	8.5
5	50	25	10	85	8.5
6	40	16	0	56	5.6
7	40	16	0	56	5.6
8	40	16	25	81	8.1
9	30	25	0	55	5.5
10	20	25	0	45	4.5
11	40	25	25	90	9.0
12	40	16	0	56	5.6
13	40	16	0	56	5.6
14	40	25	0	65	6.5
15	50	25	25	100	10.0
16	40	16	0	56	5.6
17	40	16	25	81	8.1
18	40	25	25	90	9.0

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100}\ (10)\ (\text{Normalizing Factor})^*$$

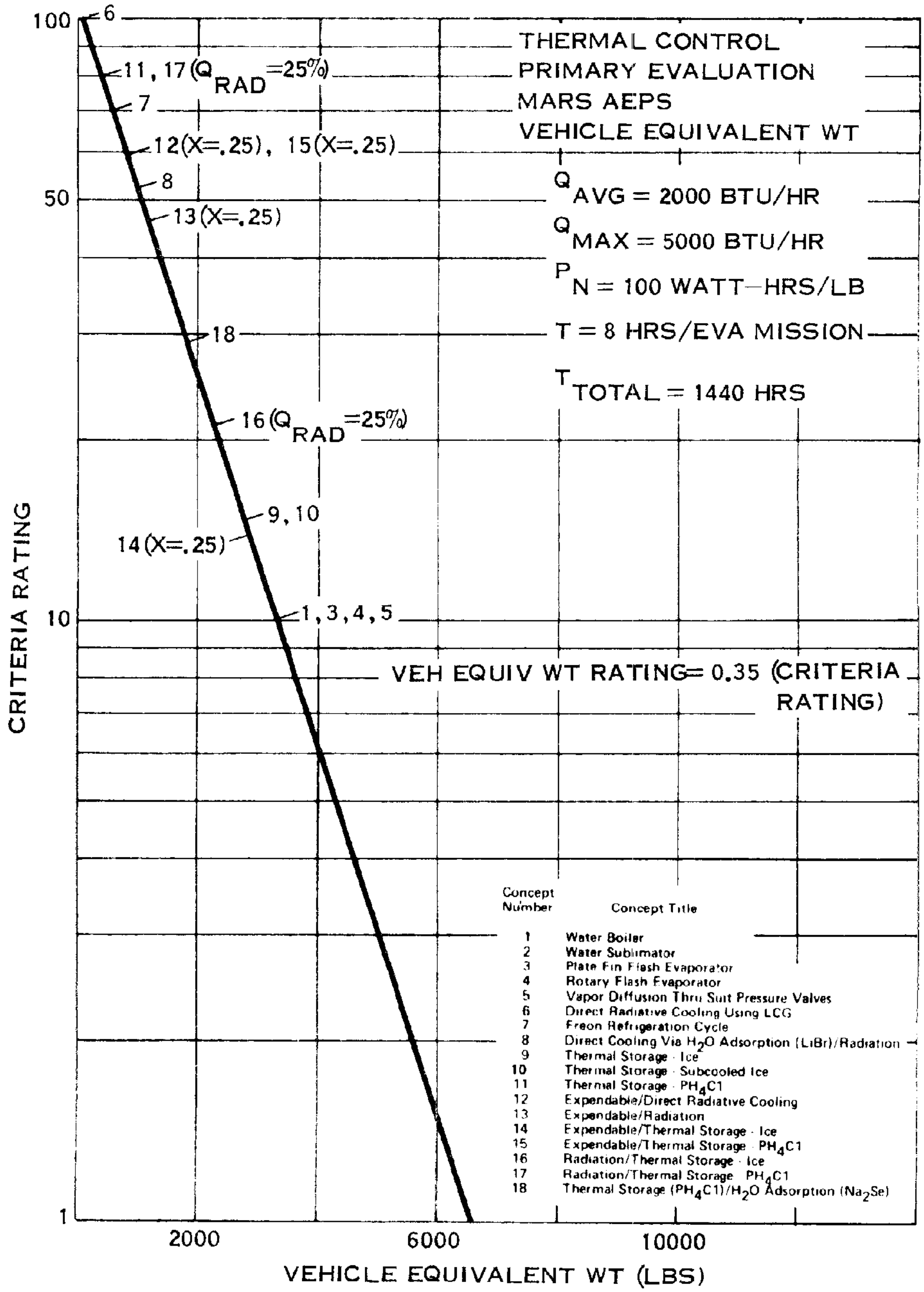
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

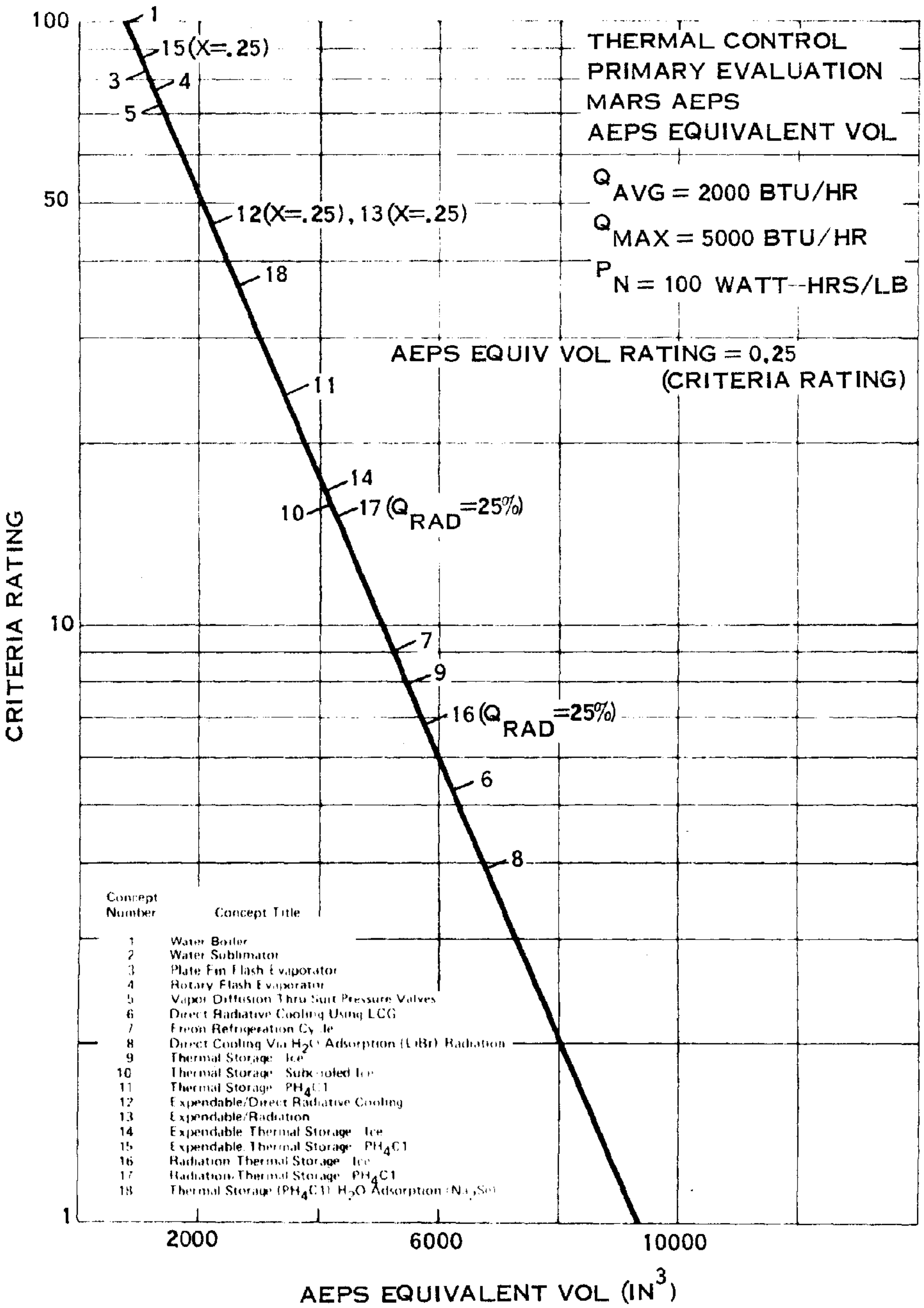
THERMAL CONTROL
PRIMARY EVALUATION - LUNAR BASE AEPS

SUMMARY

Concept	CRITERIA AEPS Vol.	Veh. Wt.	Reliability	Operability	Flex.	Total
1	25.0	3.5	12.6	15.0	7.5	63.6
2	22.5	3.5	13.9	14.9	6.6	61.4
3	20.2	3.5	10.2	14.6	8.5	57.0
4	19.3	3.5	9.3	14.4	8.5	55.0
5	18.0	3.5	1.7	11.3	8.5	43.0
6	.25	35.0	13.9	10.9	5.6	65.6
7	1.8	24.9	13.2	10.4	5.6	56.0
8	.44	18.6	10.9	5.5	8.1	43.5
9	2.0	5.6	12.6	8.2	5.5	33.9
10	3.8	5.6	6.3	6.1	4.5	26.3
11	5.8	28.0	10.2	12.9	9.0	65.9
12	7.3	21.0	15.0	10.6	5.6	59.5
13	9.5	16.1	12.4	10.3	5.6	53.9
14	4.1	5.3	10.8	8.4	6.5	35.1
15	21.3	21.0	9.3	13.9	10.0	75.5
16	1.6	7.7	11.9	6.7	5.6	33.5
17	3.8	28.0	9.3	10.6	8.1	59.8
18	8.5	9.8	9.3	8.2	9.0	44.8

MARS


THERMAL CONTROL
PRIMARY EVALUATION
MARS AEPS
VEHICLE EQUIVALENT WT
Q AVG = 2000 BTU/HR
Q MAX = 5000 BTU/HR
P N = 100 WATT–HRS/LB
T = 8 HRS/EVA MISSION
T TOTAL = 1440 HRS
VEH EQUIV WT RATING = 0.35 (CRITERIA RATING)
CRITERIA RATING
100
50
10
1
2000
6000
10000
VEHICLE EQUIVALENT WT (LBS)
6
11, 17 (Q RAD =25%)
7
12(X=.25), 15(X=.25)
8
13 (X=.25)
18
16 (Q RAD =25%)
9, 10
14 (X=.25)
1, 3, 4, 5
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H2O Adsorption (LiBr)/Radiation
9 Thermal Storage - Ice
10 Thermal Storage - Subcooled Ice
11 Thermal Storage - PH4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage - Ice
15 Expendable/Thermal Storage - PH4C1
16 Radiation/Thermal Storage - Ice
17 Radiation/Thermal Storage - PH4C1
18 Thermal Storage (PH4C1)/H2O Adsorption (Na2Se)



THERMAL CONTROL
PRIMARY EVALUATION
MARS AEPS
AEPS EQUIVALENT VOL
$Q_{AVG} = 2000$ BTU/HR
$Q_{MAX} = 5000$ BTU/HR
$P_N = 100$ WATT--HRS/LB
AEPS EQUIV VOL RATING = 0.25
(CRITERIA RATING)
1
15(X=.25)
3
4
5
12(X=.25), 13(X=.25)
18
11
14
10
17 (Q_{RAD}=25%)
7
9
16 (Q_{RAD}=25%)
6
8
100
50
10
1
2000
6000
10000
CRITERIA RATING
AEPS EQUIVALENT VOL (IN^3)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2Se)

THERMAL CONTROL
PRIMARY EVALUATION - MARS AEPS

RELIABILITY

Concept	Rating
1	12.6
3	10.2
4	9.3
5	1.7
6	13.9
7	13.2
8	10.9
9	12.6
10	6.3
11	10.2
12	15.0
13	12.4
14	10.8
15	9.3
16	11.9
17	9.3
18	9.3

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

THERMAL CONTROL
PRIMARY EVALUATION - MARS AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	4	14	10	5	25	25	98	15
3	15	4	12	10	4	25	25	95	14.6
4	15	4	11	10	4	25	25	94	14.4
5	7	4	3	10	5	20	25	74	11.3
6	5	5	15	1	5	25	15	71	10.9
7	5	5	14	1	5	23	15	68	10.4
8	5	1	8	1	1	5	15	35	5.5
9	13	3.5	10	2	3	7	15	53.5	8.2
10	14	1	7	2	1	0	15	40	6.1
11	14	5	13	2	5	25	20	84	12.9
12	5	4	14	1	5	25	15	69	10.6
13	5	4	12	1	5	25	15	67	10.3
14	14	3	8	2	3	5	20	55	8.4
15	15	4	12	10	5	25	20	91	13.9
16	5	3.5	9	1	3	7	15	43.5	6.7
17	5	5	13	1	5	25	15	69	10.6
18	14.5	1	7	5	1	5	20	53.5	8.2

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

$$\text{Operability Rating} = \frac{\text{total}}{100}\ (15)\ \ (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

THERMAL CONTROL
PRIMARY EVALUATION - MARS AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
3	50	25	10	85	8.5
4	50	25	10	85	8.5
5	50	25	10	85	8.5
6	40	16	0	56	5.6
7	40	16	0	56	5.6
8	40	16	25	81	8.1
9	30	25	0	55	5.5
10	20	25	0	45	4.5
11	40	25	25	90	9.0
12	40	16	0	56	5.6
13	40	16	0	56	5.6
14	40	25	0	65	6.5
15	50	25	25	100	10.0
16	40	16	0	56	5.6
17	40	16	25	81	8.1
18	40	25	25	90	9.0

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100}\ (10)\ (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

THERMAL CONTROL
PRIMARY EVALUATION - MARS AEPS

SUMMARY

Concept	CRITERIA					Total
	AEPS Vol.	Veh. Wt.	Reliability	Operability	Flex.	
1	25.0	3.5	12.6	15.0	7.5	63.6
3	20.2	3.5	10.2	14.6	8.5	57.0
4	19.3	3.5	9.3	14.4	8.5	55.0
5	18.0	3.5	1.7	11.3	8.5	43.0
6	1.3	35.0	13.9	10.9	5.6	66.7
7	2.2	24.9	13.2	10.4	5.6	56.3
8	1.0	18.6	10.9	5.5	8.1	44.1
9	2.0	5.6	12.6	8.2	5.5	33.9
10	3.8	5.6	6.3	6.1	4.5	26.3
11	5.8	28.0	10.2	12.9	9.0	65.9
12	11.0	21.0	15.0	10.6	5.6	63.2
13	11.0	16.1	12.4	10.3	5.6	55.4
14	4.1	5.3	10.8	8.4	6.5	35.1
15	21.3	21.0	9.3	13.9	10.0	75.5
16	1.7	7.7	11.9	6.7	5.6	33.6
17	3.8	28.0	9.3	10.6	8.1	59.8
18	8.5	9.8	9.3	8.2	9.0	44.8

5.1.1.3 CO_2 Control/O_2 Supply - Table 5-4 is an index of the sixteen (16) candidate CO_2 control/O_2 supply concepts that passed the go/no go evaluation and were carried into the primary evaluation. All sixteen concepts were considered for the Space Station and Lunar Base missions; however, the AEPS regenerable CO_2 control concepts were omitted for consideration on Mars due to the presence of the CO_2 rich ambient environment.

TABLE 5-4

CO_2 CONTROL/O_2 SUPPLY CONCEPT INDEX

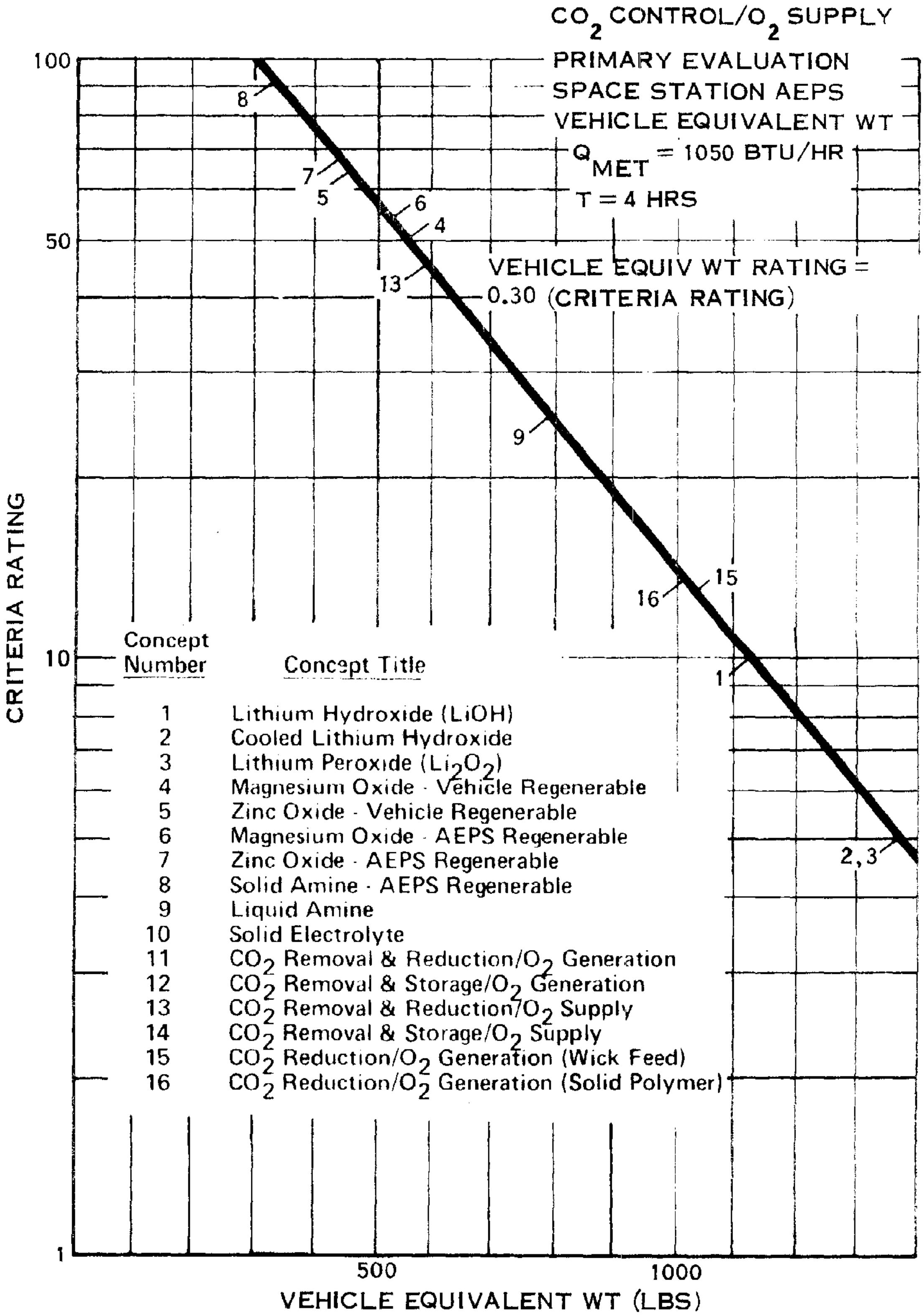
Concept Number	Concept Title
1	Lithium Hydroxide (LiOH)
2	Cooled Lithium Hydroxide
3	Lithium Peroxide (Li_2O_2)
4	Magnesium Oxide - Vehicle Regenerable
5	Zinc Oxide - Vehicle Regenerable
6	Magnesium Oxide - AEPS Regenerable
7	Zinc Oxide - AEPS Regenerable
8	Solid Amine - AEPS Regenerable
9	Liquid Amine
10	Solid Electrolyte
11	CO_2 Removal & Reduction/O_2 Generation
12	CO_2 Removal & Storage/O_2 Generation
13	CO_2 Removal & Reduction/O_2 Supply
14	CO_2 Removal & Storage/O_2 Supply
15	CO_2 Reduction/O_2 Generation (Wick Feed)
16	CO_2 Reduction/O_2 Generation (Solid Polymer)

The following six (6) concepts passed the primary evaluation and were carried into the secondary evaluation:

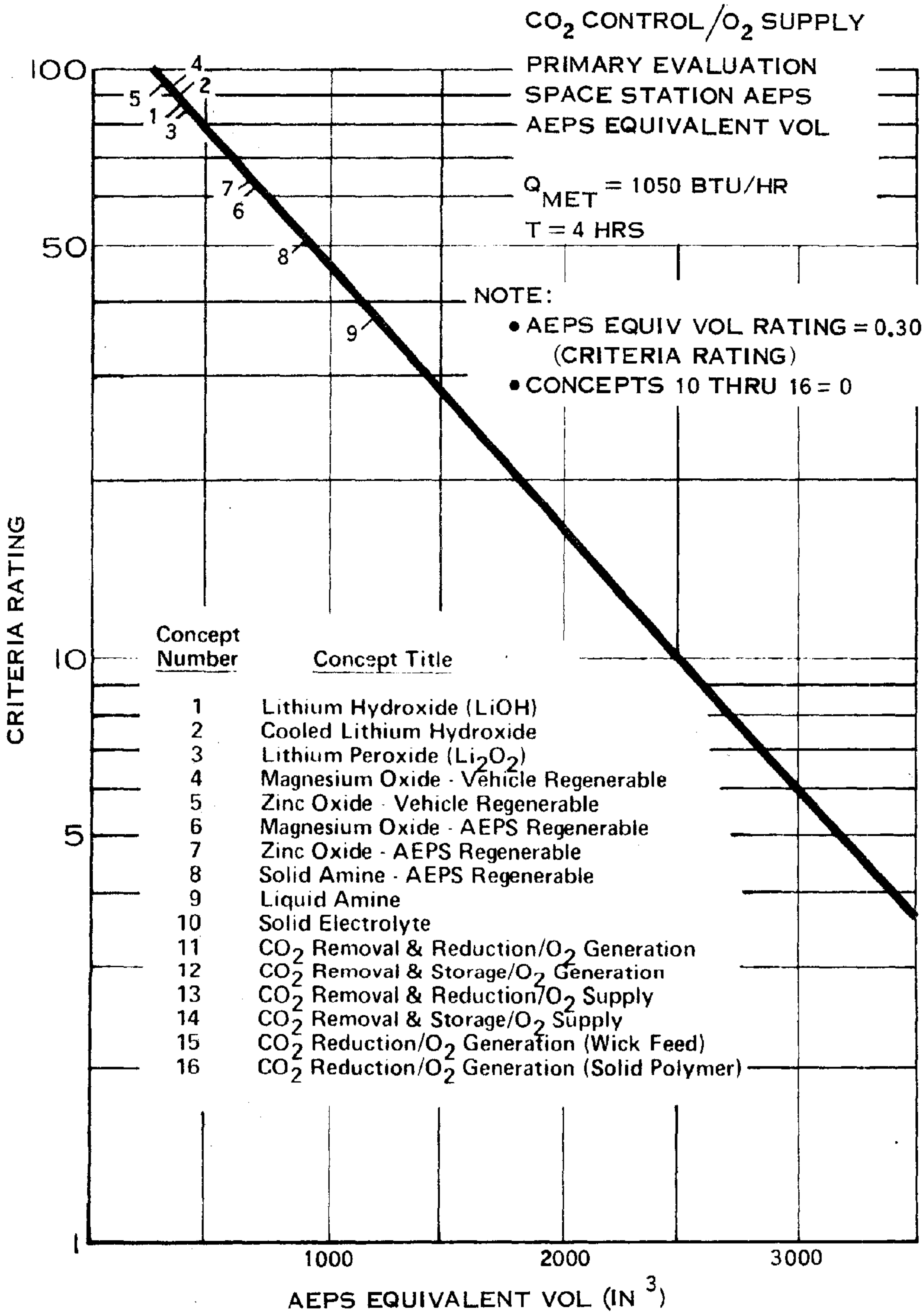
a. Lithium Hydroxide (LiOH)
b. Magnesium Oxide - Vehicle Regenerable
c. Zinc Oxide - Vehicle Regenerable
d. Magnesium Oxide - AEPS Regenerable
e. Zinc Oxide - AEPS Regenerable
f. Solid Amine - AEPS Regenerable

Implementation of the primary evaluation criteria and the resultant candidate CO_2 control/O_2 supply concept ratings are presented in detail on the following pages.

SPACE STATION



CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION
SPACE STATION AEPS
VEHICLE EQUIVALENT WT
Q_{MET} = 1050 BTU/HR
T = 4 HRS
VEHICLE EQUIV WT RATING = 0.30 (CRITERIA RATING)
CRITERIA RATING
VEHICLE EQUIVALENT WT (LBS)
100
50
10
1
500
1000
8
7
5
6
4
13
9
16
15
1
2,3
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)



CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION
SPACE STATION AEPS
AEPS EQUIVALENT VOL
Q_{MET} = 1050 BTU/HR
T = 4 HRS
NOTE:
• AEPS EQUIV VOL RATING = 0.30 (CRITERIA RATING)
• CONCEPTS 10 THRU 16 = 0
CRITERIA RATING
AEPS EQUIVALENT VOL (IN ^{3})
100
50
10
5
1
1000
2000
3000
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - SPACE STATION AEPS

RELIABILITY

Concept	Rating
1	15.0
2	15.0
3	12.0
4	10.7
5	10.7
6	7.2
7	7.2
8	9.5
9	6.4
10	4.5
11	3.0
12	3.3
13	5.5
14	5.5
15	3.8
16	3.8

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem conponents and the number of subsystem component failures that could cause mission abort and/or loss of life.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - SPACE STATION AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	5	15	10	5	10	25	85	13.8
2	15	5	13	10	5	5	25	68	10.4
3	15	2	10	10	3	5	20	65	9.9
4	15	5	13	10	5	10	25	83	12.6
5	15	5	13	10	5	10	25	83	12.6
6	15	5	10	10	5	20	25	90	13.7
7	15	5	10	10	5	20	25	90	13.7
8	15	5	13	10	5	25	25	98	15.0
9	10	2	5	5	1	20	25	68	10.4
10	5	1	1	1	1	7	25	41	6.4
11	5	1	1	1	2	10	25	45	7.0
12	5	1	1	1	4	7	25	44	6.8
13	5	1	1	1	2	7	25	42	6.5
14	5	1	1	1	4	5	25	42	6.5
15	5	1	1	1	2	7	25	42	6.5
16	5	1	1	1	2	7	25	42	6.5

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

Operability Rating $= \frac{\text{total}}{100}$ (15) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - SPACE STATION AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	25	0	75	7.5
3	50	25	15	90	9.0
4	50	25	25	100	10.0
5	50	25	25	100	10.0
6	50	17	25	92	9.2
7	50	17	25	92	9.2
8	50	17	25	92	9.2
9	50	17	25	92	9.2
10	10	15	25	50	5.0
11	10	15	25	50	5.0
12	10	15	25	50	5.0
13	10	15	25	50	5.0
14	10	15	25	50	5.0
15	10	15	25	50	5.0
16	10	15	25	50	5.0

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

Flexibility Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

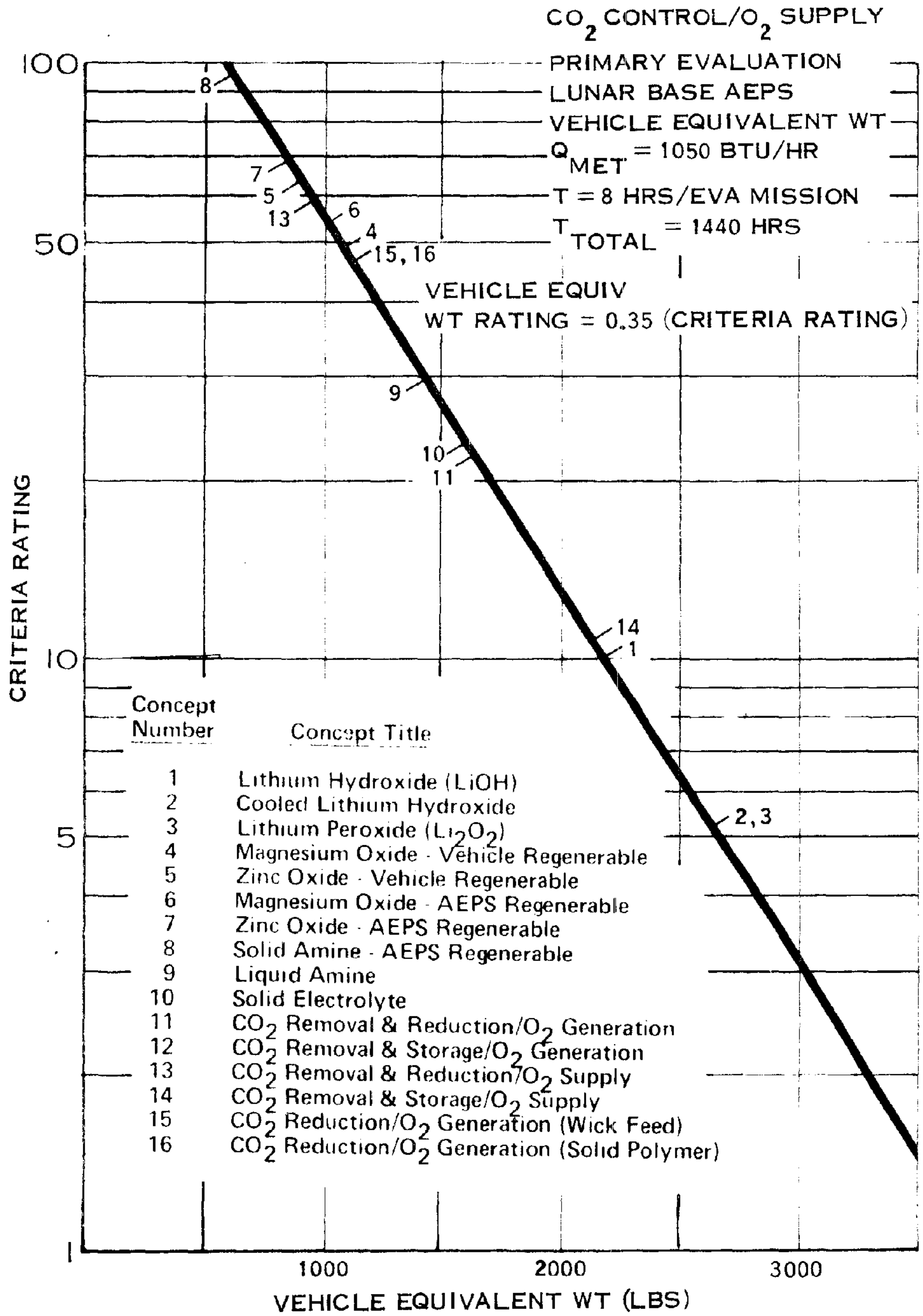
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - SPACE STATION AEPS

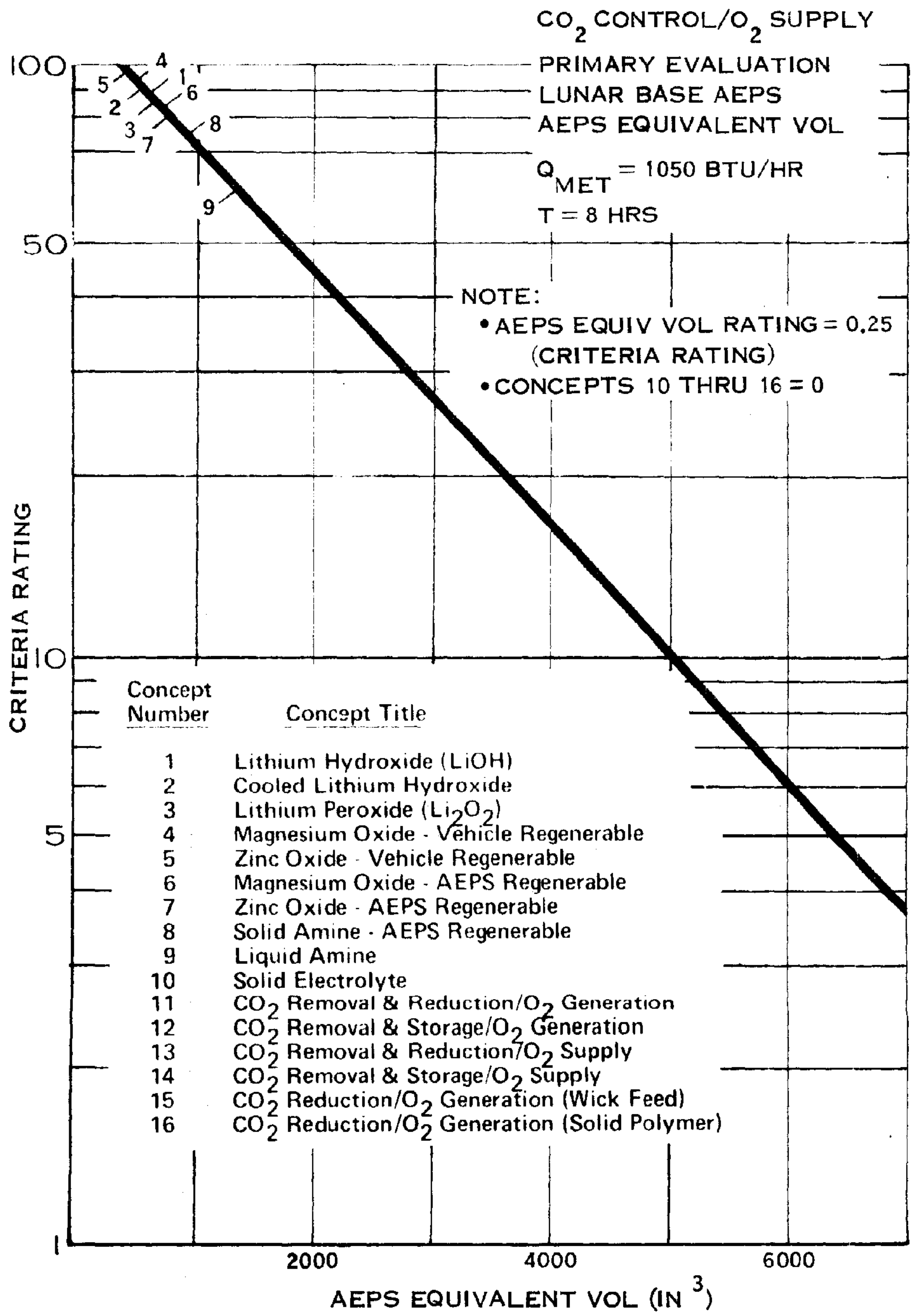
SUMMARY

	Criteria					
Concept	AEPS Vol.	Veh. Wt.	Reliability	Operability	Flexibility	Total
1	25.8	3.0	15.0	13.0	7.5	64.3
2	26.7	1.5	15.0	10.4	7.5	61.1
3	25.2	1.5	12.0	9.9	9.0	57.6
4	27.0	15.0	10.7	12.6	10.0	75.3
5	28.2	19.5	10.7	12.6	10.0	81.0
6	18.9	16.2	7.2	13.7	9.2	65.2
7	19.2	20.4	7.2	13.7	9.2	69.7
8	15.3	27.6	9.5	15.0	9.2	76.6
9	1.1	7.8	6.4	10.4	9.2	34.9
10	0	0	4.5	6.4	5.0	15.9
11	0	0	3.0	7.0	5.0	15.0
12	0	0	3.3	6.8	5.0	15.1
13	0	13.5	5.5	6.5	5.0	30.5
14	0	0	5.5	6.5	5.0	17.0
15	0	3.9	3.8	6.5	5.0	19.2
16	0	4.1	3.8	6.5	5.0	19.4

LUNAR BASE



CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION
LUNAR BASE AEPS
VEHICLE EQUIVALENT WT
Q_{MET} = 1050 BTU/HR
T = 8 HRS/EVA MISSION
T_{TOTAL} = 1440 HRS
VEHICLE EQUIV
WT RATING = 0.35 (CRITERIA RATING)
CRITERIA RATING
VEHICLE EQUIVALENT WT (LBS)
100
50
10
5
1
1000
2000
3000
8
7
5
13
6
4
15, 16
9
10
11
14
1
2, 3
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)



CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION
LUNAR BASE AEPS
AEPS EQUIVALENT VOL
Q_{MET} = 1050 BTU/HR
T = 8 HRS
NOTE:
• AEPS EQUIV VOL RATING = 0.25 (CRITERIA RATING)
• CONCEPTS 10 THRU 16 = 0
CRITERIA RATING
100
50
10
5
1
2000
4000
6000
AEPS EQUIVALENT VOL (IN^3)
1
2
3
4
5
6
7
8
9
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - LUNAR BASE AEPS

RELIABILITY

Concept	Rating
1	15.0
2	15.0
3	12.0
4	10.7
5	10.7
6	7.2
7	7.2
8	9.5
9	6.4
10	4.5
11	3.0
12	3.3
13	5.5
14	5.5
15	3.8
16	3.8

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - LUNAR BASE AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	5	15	10	5	10	25	85	13.8
2	15	5	13	10	5	5	25	68	10.4
3	15	2	10	10	3	5	20	65	9.9
4	15	5	13	10	5	10	25	83	12.6
5	15	5	13	10	5	10	25	83	12.6
6	15	5	10	10	5	20	25	90	13.7
7	15	5	10	10	5	20	25	90	13.7
8	15	5	13	10	5	25	25	98	15.0
9	10	2	5	5	1	20	25	68	10.4
10	5	1	1	1	1	7	25	41	6.4
11	5	1	1	1	2	10	25	45	7.0
12	5	1	1	1	4	7	25	44	6.8
13	5	1	1	1	2	7	25	42	6.5
14	5	1	1	1	4	5	25	42	6.5
15	5	1	1	1	2	7	25	42	6.5
16	5	1	1	1	2	7	25	42	6.5

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

$$\text{Operability Rating} = \frac{\text{total}}{100} \ (15) \ (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - LUNAR BASE AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	25	0	75	7.5
3	50	25	15	90	9.0
4	50	25	25	100	10.0
5	50	25	25	100	10.0
6	50	17	25	92	9.2
7	50	17	25	92	9.2
8	50	17	25	92	9.2
9	50	17	25	92	9.2
10	10	15	25	50	5.0
11	10	15	25	50	5.0
12	10	15	25	50	5.0
13	10	15	25	50	5.0
14	10	15	25	50	5.0
15	10	15	25	50	5.0
16	10	15	25	50	5.0

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100} \ (10) \ (\text{Normalizing Factor})^*$$

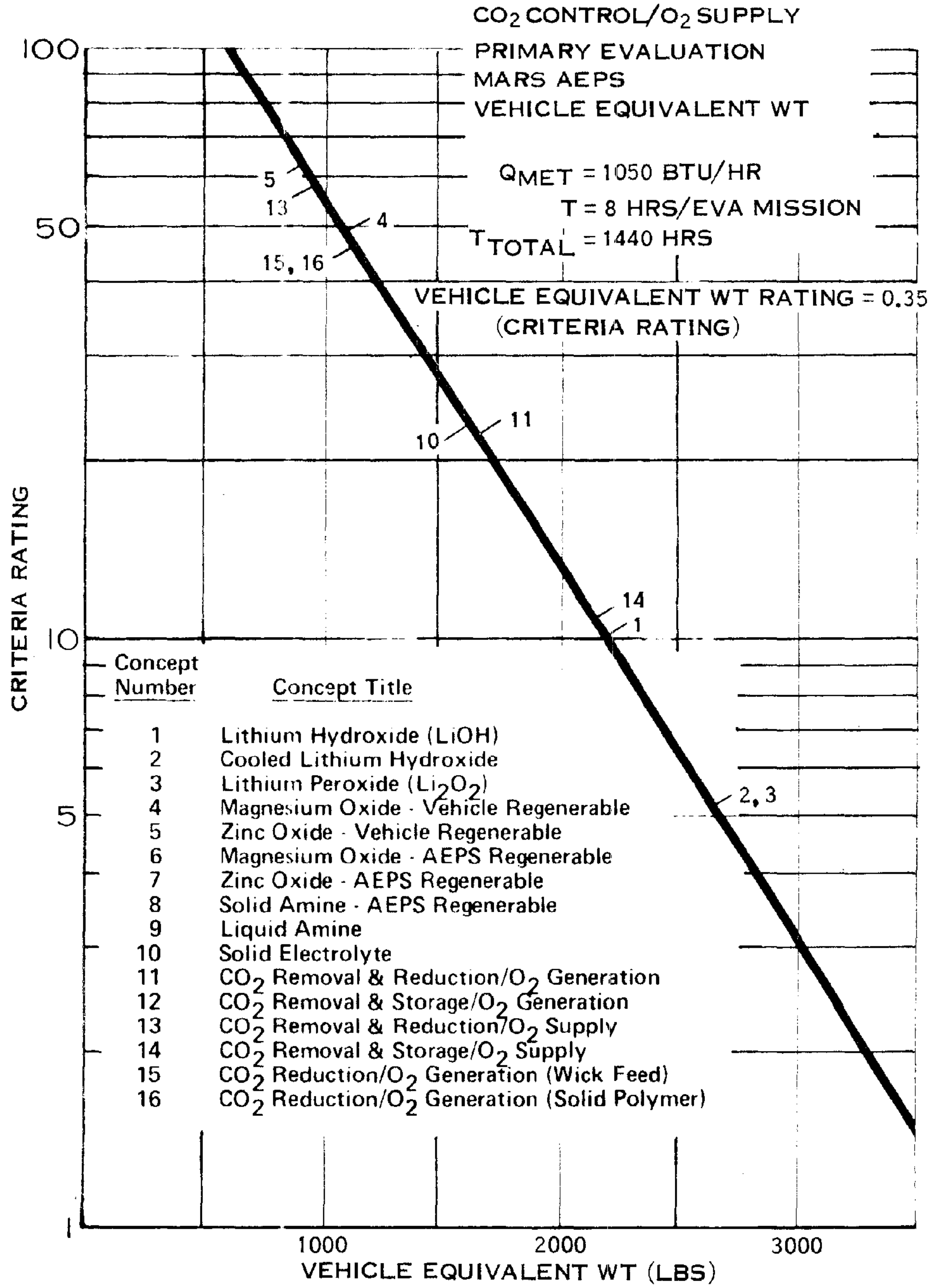
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

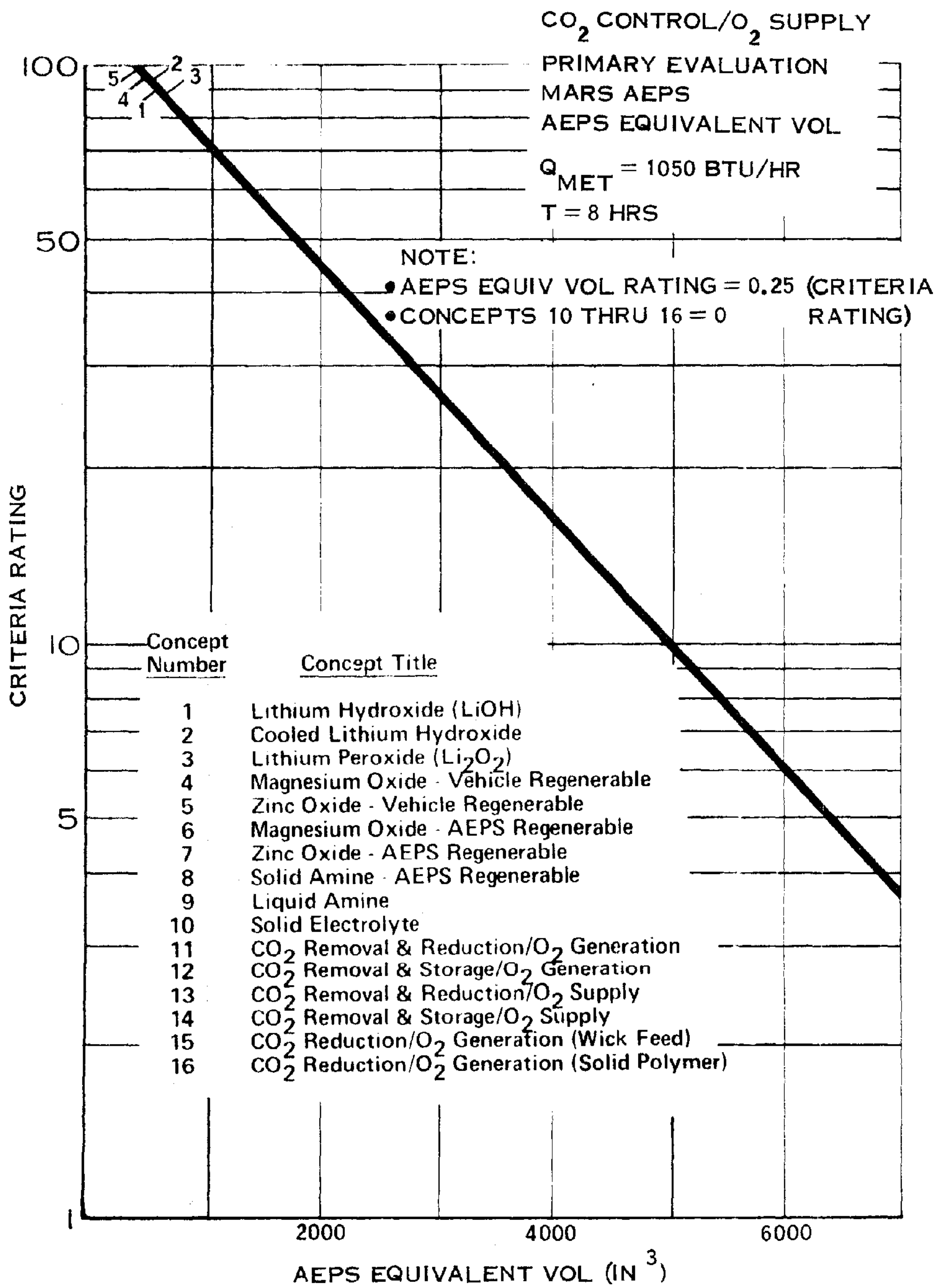
CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - LUNAR BASE AEPS

SUMMARY

Concept	Criteria: AEPS Vol.	Veh. Wt.	Reliability	Operability	Flexibility	Total
1	22.3	3.5	15.0	13.0	7.5	61.3
2	23.0	1.8	15.0	10.4	7.5	57.7
3	21.8	1.8	12.0	9.9	9.0	54.5
4	23.5	17.2	10.7	12.6	10.0	74.0
5	24.3	22.1	10.7	12.6	10.0	79.7
6	20.5	18.9	7.2	13.7	9.2	69.5
7	21.0	24.1	7.2	13.7	9.2	75.2
8	19.0	33.6	9.5	15.0	9.2	86.3
9	15.3	10.5	6.4	10.4	9.2	51.8
10	0	8.1	4.5	6.4	5.0	24.0
11	0	7.7	3.0	7.0	5.0	22.7
12	0	1.2	3.3	6.8	5.0	16.3
13	0	20.7	5.5	6.5	5.0	37.7
14	0	3.7	5.5	6.5	5.0	20.7
15	0	16.5	3.8	6.5	5.0	31.8
16	0	16.5	3.8	6.5	5.0	31.8

MARS


CO2 CONTROL/O2 SUPPLY
PRIMARY EVALUATION
MARS AEPS
VEHICLE EQUIVALENT WT
QMET = 1050 BTU/HR
T = 8 HRS/EVA MISSION
TTOTAL = 1440 HRS
VEHICLE EQUIVALENT WT RATING = 0.35
(CRITERIA RATING)
CRITERIA RATING
VEHICLE EQUIVALENT WT (LBS)
100
50
10
5
1
1000
2000
3000
5
13
4
15, 16
10
11
14
1
2, 3
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li2O2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO2 Removal & Reduction/O2 Generation
12 CO2 Removal & Storage/O2 Generation
13 CO2 Removal & Reduction/O2 Supply
14 CO2 Removal & Storage/O2 Supply
15 CO2 Reduction/O2 Generation (Wick Feed)
16 CO2 Reduction/O2 Generation (Solid Polymer)


CO2 CONTROL/O2 SUPPLY
PRIMARY EVALUATION
MARS AEPS
AEPS EQUIVALENT VOL
Q_{MET} = 1050 BTU/HR
T = 8 HRS
NOTE:
• AEPS EQUIV VOL RATING = 0.25 (CRITERIA RATING)
• CONCEPTS 10 THRU 16 = 0
CRITERIA RATING
100
50
10
5
1
2000
4000
6000
AEPS EQUIVALENT VOL (IN^3)
1
2
3
4
5
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - MARS AEPS

RELIABILITY

Concept	Rating
1	15.0
2	15.0
3	12.0
4	10.7
5	10.7
10	4.5
11	3.0
12	3.3
13	5.5
14	5.5
15	3.8
16	3.8

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - MARS AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	5	15	10	5	10	25	85	13.8
2	15	5	13	10	5	5	25	68	10.4
3	15	2	10	10	3	5	20	65	9.9
4	15	5	13	10	5	10	25	83	12.6
5	15	5	13	10	5	10	25	83	12.6
10	5	1	1	1	1	7	25	41	6.4
11	5	1	1	1	2	10	25	45	7.0
12	5	1	1	1	4	7	25	44	6.8
13	5	1	1	1	2	7	25	42	6.5
14	5	1	1	1	4	5	25	42	6.5
15	5	1	1	1	2	7	25	42	6.5
16	5	1	1	1	2	7	25	42	6.5

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

$$\text{Operability Rating} = \frac{\text{total}}{100}\ (15)\ (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - MARS AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	25	0	75	7.5
3	50	25	15	90	9.0
4	50	25	25	100	10.0
5	50	25	25	100	10.0
10	10	15	25	50	5.0
11	10	15	25	50	5.0
12	10	15	25	50	5.0
13	10	15	25	50	5.0
14	10	15	25	50	5.0
15	10	15	25	50	5.0
16	10	15	25	50	5.0

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100} \quad (10) \quad (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

CO_2 CONTROL/O_2 SUPPLY
PRIMARY EVALUATION - MARS AEPS

SUMMARY

Concept	Criteria: AEPS Vol.	Veh. Wt.	Reliability	Operability	Flexibility	Total
1	22.3	3.5	15.0	13.0	7.5	61.3
2	23.0	1.8	15.0	10.4	7.5	57.7
3	21.8	1.8	12.0	9.9	9.0	54.5
4	23.5	17.2	10.7	12.6	10.0	74.0
5	24.3	22.1	10.7	12.6	10.0	79.7
10	0	8.1	4.5	6.4	5.0	24.0
11	0	7.7	3.0	7.0	5.0	22.7
12	0	1.2	3.3	6.8	5.0	16.3
13	0	20.7	5.5	6.5	5.0	37.7
14	0	3.7	5.5	6.5	5.0	20.7
15	0	16.5	3.8	6.5	5.0	31.8
16	0	16.5	3.8	6.5	5.0	31.8

5.1.2 Secondary Evaluation

5.1.2.1 General - The secondary evaluation represents a step in depth of competitive evaluation which is taken if no clear-cut selection is available from the primary evaluation. Ratings of the candidate concepts against secondary characteristics are relative assessments within each area of consideration and, as in the implementation of the primary criteria, each candidate concept receives a rating of from 0 to 100 for each criterion. Each rating is then multiplied by the weighting factors defined in Table 5-5 and the ratings added to obtain a total rating for each candidate concept. A concurrent review of both the primary and secondary evaluation results is then conducted. Those concepts which score relatively high in both evaluations are considered to have passed the secondary evaluation; those that score relatively low in both evaluations are rejected and eliminated from further consideration.

In any event, the secondary criteria are applied against all recommended concepts to provide a systematic review of the overall acceptability of these selected concepts and to ensure that these characteristics would not preclude their use.

The secondary criteria are defined as follows:

Vehicle Equivalent Volume - Vehicle equivalent volume is a volumetric measure of the subsystem, expendables, recharge and/or regeneration equipment, power penalty, heat rejection penalty, and special interface equipment, and is a "second-order" tool which provides an objective quantitative basis for evaluation.

AEPS Equivalent Weight - Since this criterion is directly considered in the primary criteria of vehicle equivalent weight, the primary emphasis of weight in the secondary criteria is the limiting factor of ability to handle, service, move, replace, and/or install the equipment and the effect upon the total EVA system (including AEPS, space suit, etc.) center of gravity.

Interface Compatibility - This is a measure of the ability of the concept to integrate with other subsystems or components, the crew, the space suit and the vehicle without a severe penalty on the other areas. Because of the physical and functional scope of an AEPS, an interface check is necessary to assure that no unreasonable problems are encountered in eventual integration of the AEPS in the total mission/vehicle system.

Maintainability - Maintainability is a measure of the time required for checkout, replacement of expendables, regeneration of components or subsystems, cleaning, and scheduled and unscheduled maintenance where such operations are required. This assessment is made after a satisfactory design concept is evolved with respect to performance, spares, redundancy, and modularity.

Cost - Cost is a secondary criterion since the mission must first be achieved. If two or more competing concepts can achieve the mission, then cost differences are considered as a significant basis for decision.

7 4

5.2.1 (continued)

TABLE 5-5 SECONDARY CRITERIA WEIGHTING FACTORS

	Weighting Factors		
	Space Station	Lunar Base	Mars Landing
Vehicle Equivalent Volume	0.30	0.30	0.30
AEPS Equivalent Weight	0.15	0.20	0.20
Interface Compatibility	0.25	0.20	0.20
Maintainability	0.20	0.20	0.20
Cost	0.10	0.10	0.10

The secondary criteria whose ratings were determined quantitatively are vehicle equivalent volume and AEPS equivalent weight. The competitive ratings for both these criteria were determined in a manner similar to that described for the quantitative primary criteria (see Section 5.1) and in accordance with Table 5-6.

The ratings of the three remaining secondary criteria were determined qualitatively. The interface compatibility rating was determined by dividing interface compatibility into three subareas and weighting them as follows:

A.	Other AEPS Subsystem Interfaces	20 points
B.	Crew Interfaces	50
C.	Vehicle Interfaces	30
		100 points

A relative assessment of each candidate concept was then made and the sum of the ratings of the three subareas was equal to the total interface compatibility rating for each candidate concept.

The maintainability rating was determined by dividing maintainability into three subareas and weighting each area as follows:

A.	Complexity of maintenance	40 points
B.	Average downtime	20
C.	Frequency of downtimes	40
		100 points

QUANTITATIVE SECONDARY CRITERIA RATING END POINTS

SUBSYSTEM	SECONDARY CRITERION	MISSION		
		SPACE STATION	LUNAR BASE	MARS
Thermal Control	Vehicle Equivalent Volume 100 points 10 points	 6 ft^3 45 ft^3	 6 ft^3 90 ft^3	 6 ft^3 90 ft^3
	AEPS Equivalent Weight 100 points 10 points	 12.5 lbs 40 lbs	 25 lbs 40 lbs	 25 lbs 40 lbs
CO_2 Control/O_2 Supply	Vehicle Equivalent Volume 100 points 10 points	 9000 in^3 42,500 in^3	 17,000 in^3 87,000 in^3	 17,000 in^3 87,000 in^3
	AEPS Equivalent Weight 100 points 10 points	 8 lbs 41 lbs	 12 lbs 80 lbs	 12 lbs 80 lbs

TABLE 5-6

5.1.2.1 (continued)

A relative assessment of each candidate concept was then made and the sum of the ratings of the three subareas was equal to the total maintainability rating for each candidate concept.

The cost rating was determined by dividing cost into two subareas and weighting each as follows:

A.	Recurring cost	30 points
B.	Non-recurring cost	70
		100 points

A relative assessment of each candidate concept was then made and the sum of the ratings of the two subareas was equal to the total cost rating for each candidate concept.

The rating for each secondary criterion was multiplied by the weighting factors defined in Table 5-5 and then summed up to determine the final competitive rating for each of the remaining candidate concepts.

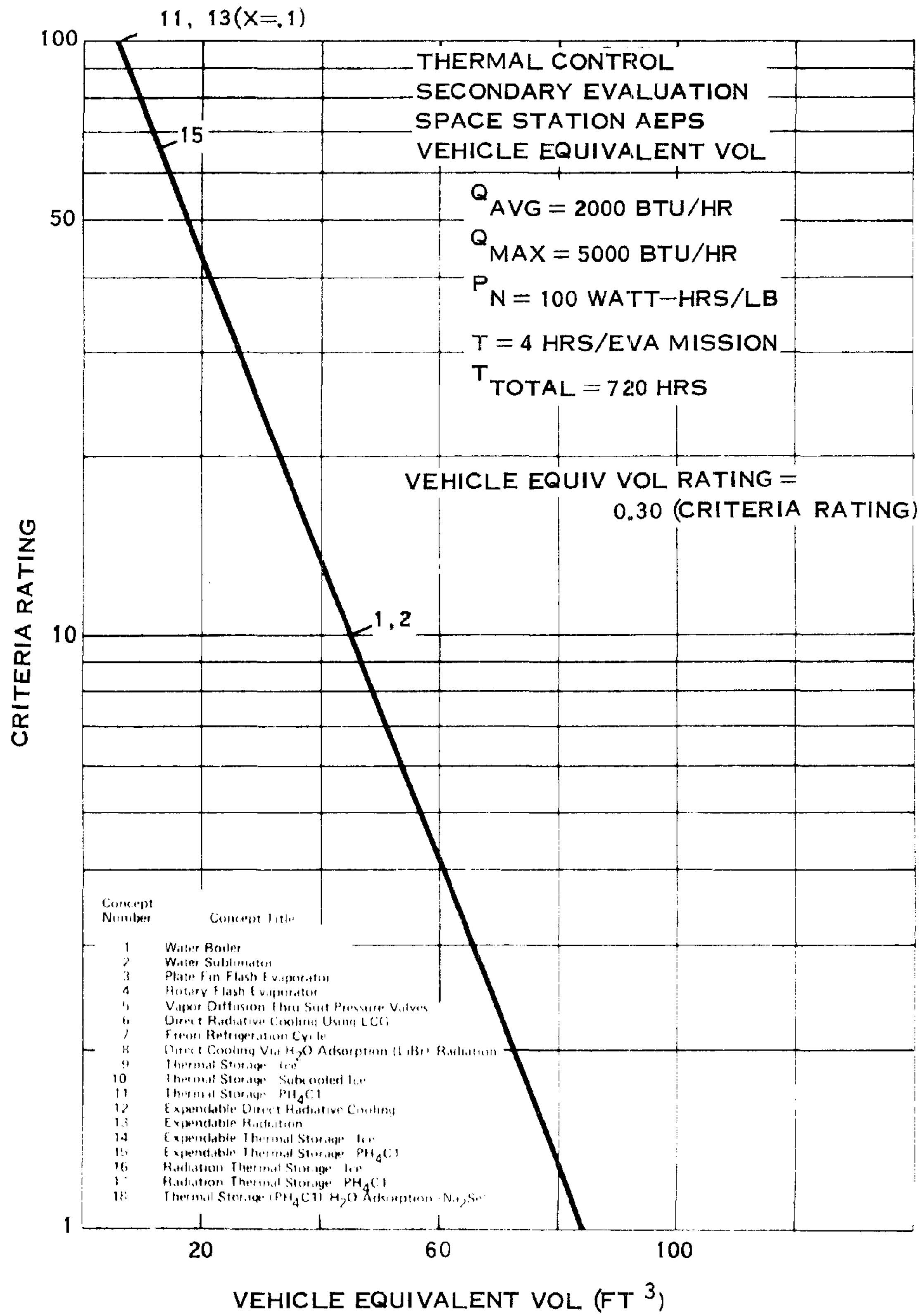
5.1.2.2 Thermal Control - Nine (9) thermal control concepts passed the primary evaluation and were carried into the secondary evaluation. Concepts 1, 2, 11, 13 and 15 were considered for Space Station, all nine were considered for Lunar Base, and all but concept 2 were considered for Mars.

The following six (6) concepts passed the secondary evaluation:

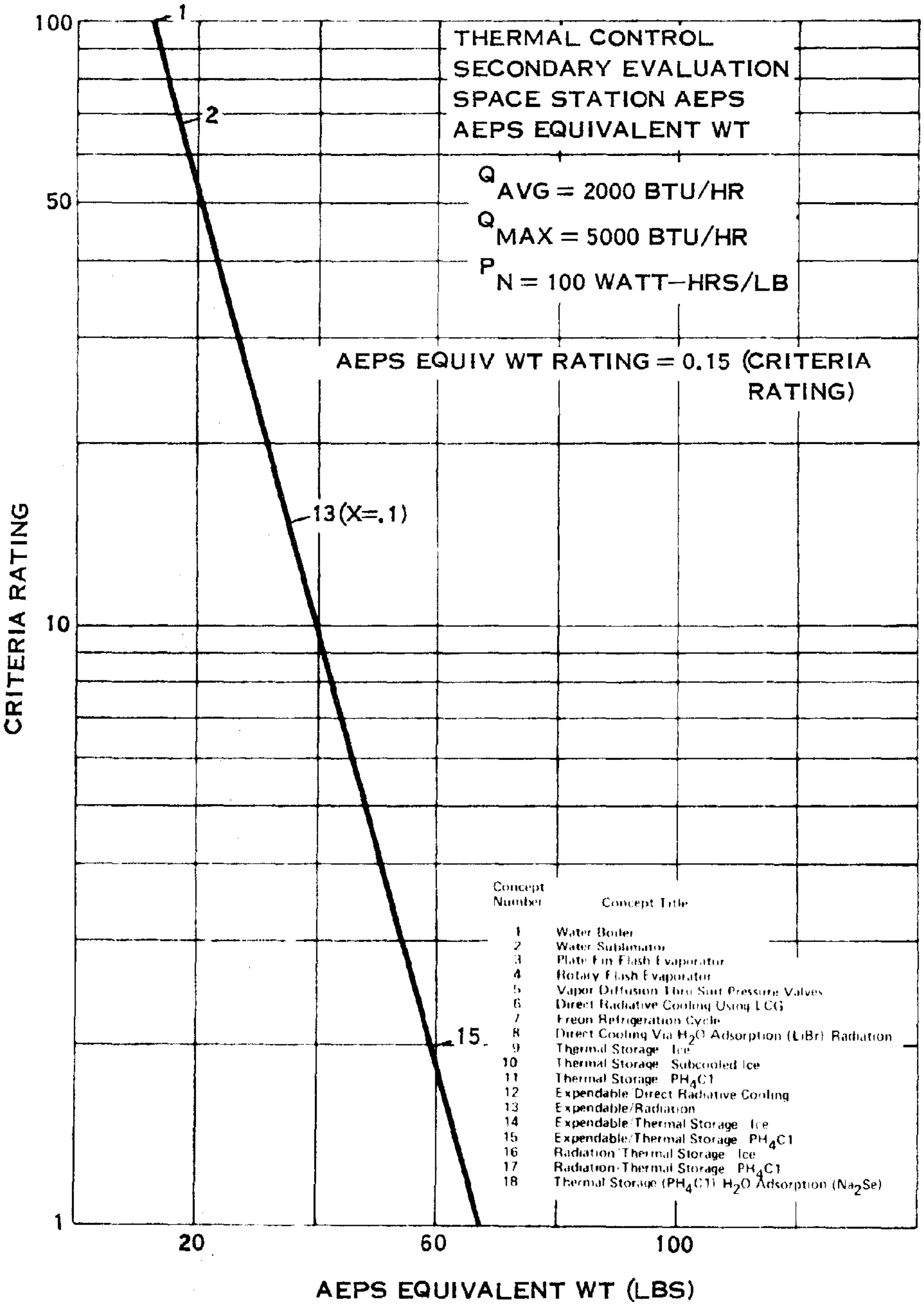
a. Water Boiler
b. Water Sublimator
c. Thermal Storage - PH_4Cl
d. Expendable/Direct Radiative Cooling
e. Expendable/Radiation
f. Expendable/Thermal Storage - PH_4Cl

Implementation of the secondary evaluation criteria and the resultant candidate thermal control concept ratings are presented in detail on the following pages.

SPACE STATION



11, 13(X=.1)
15
1, 2
THERMAL CONTROL
SECONDARY EVALUATION
SPACE STATION AEPS
VEHICLE EQUIVALENT VOL
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
T = 4 HRS/EVA MISSION
T_{TOTAL} = 720 HRS
VEHICLE EQUIV VOL RATING = 0.30 (CRITERIA RATING)
CRITERIA RATING
100
50
10
1
20
60
100
VEHICLE EQUIVALENT VOL (FT^3)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable Direct Radiative Cooling
13 Expendable Radiation
14 Expendable Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2Se)


THERMAL CONTROL
SECONDARY EVALUATION
SPACE STATION AEPS
AEPS EQUIVALENT WT
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
AEPS EQUIV WT RATING = 0.15 (CRITERIA RATING)
CRITERIA RATING
100
50
10
1
1
2
13 (X=.1)
15
20
60
100
AEPS EQUIVALENT WT (LBS)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage Ice
15 Expendable/Thermal Storage PH_4C1
16 Radiation/Thermal Storage Ice
17 Radiation/Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2Se)

THERMAL CONTROL
SECONDARY EVALUATION - SPACE STATION AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	52	20	92	25.0
2	20	52	20	92	25.0
11	20	28	28	76	20.7
13	20	10	20	50	13.6
15	20	44	20	84	23.0

Notes:

A - Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (25) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 25 points.

THERMAL CONTROL
SECONDARY EVALUATION - SPACE STATION AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
2	40	20	40	100	20.0
11	40	20	40	100	20.0
13	15	10	10	35	7.0
15	40	20	40	100	20.0

Notes:

A = Complexity of Maintenance (40 points)
B = Average Downtime (20 Points
C = Frequence of Downtimes (40 points)

$$\text{Maintainability Rating} = \frac{\text{total}}{100} (20) \quad (\text{Normalizing Factor})^{*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

THERMAL CONTROL
SECONDARY EVALUATION - SPACE STATION AEPS

COST

Concept	A	B	Total	Rating
1	30	70	100	10.0
2	30	70	100	10.0
11	15	0	15	1.5
13	15	50	65	6.5
15	10	0	10	1.0

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating $= \frac{\text{total}}{100}$ (10) (Normalizing Factor)*

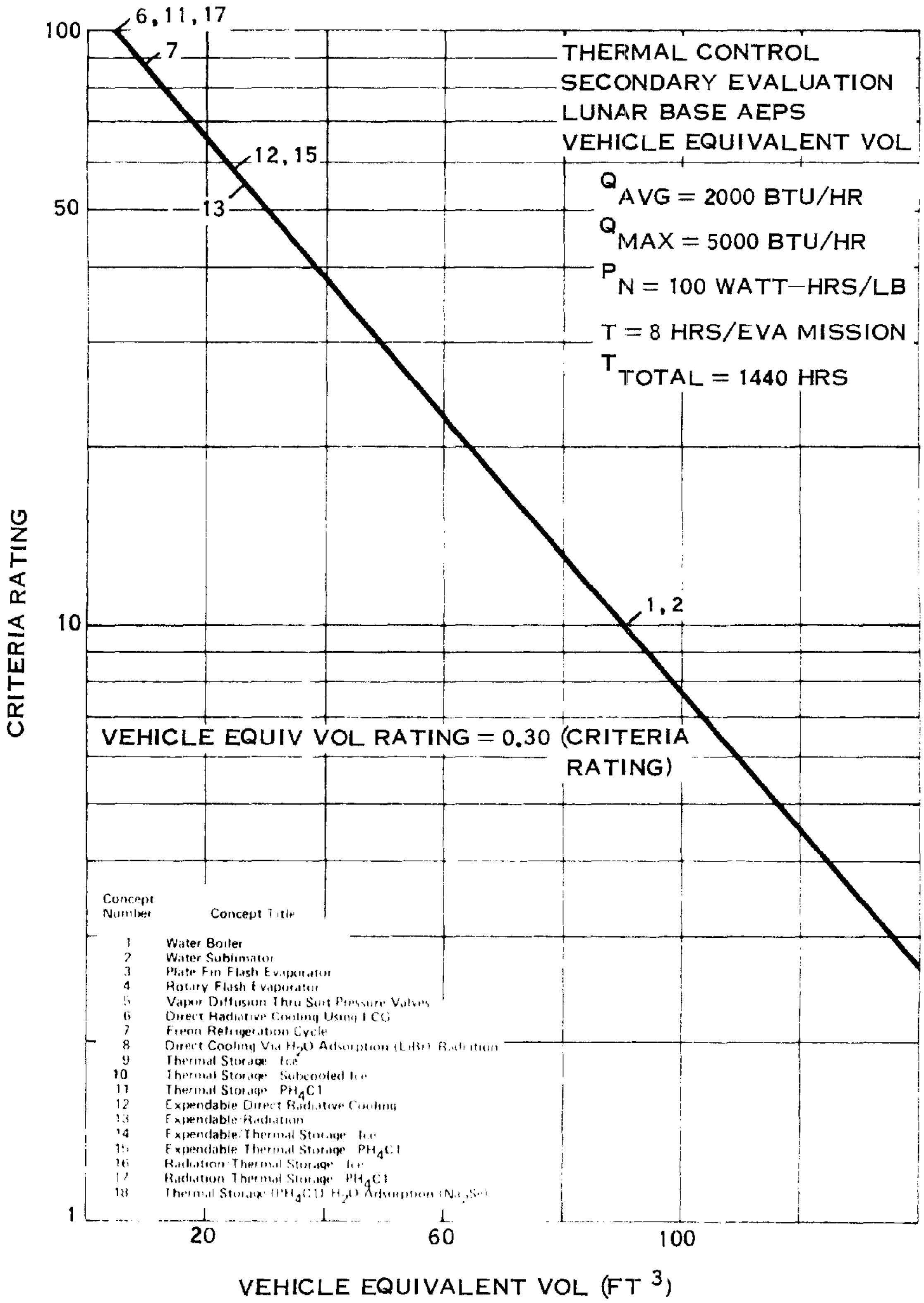
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

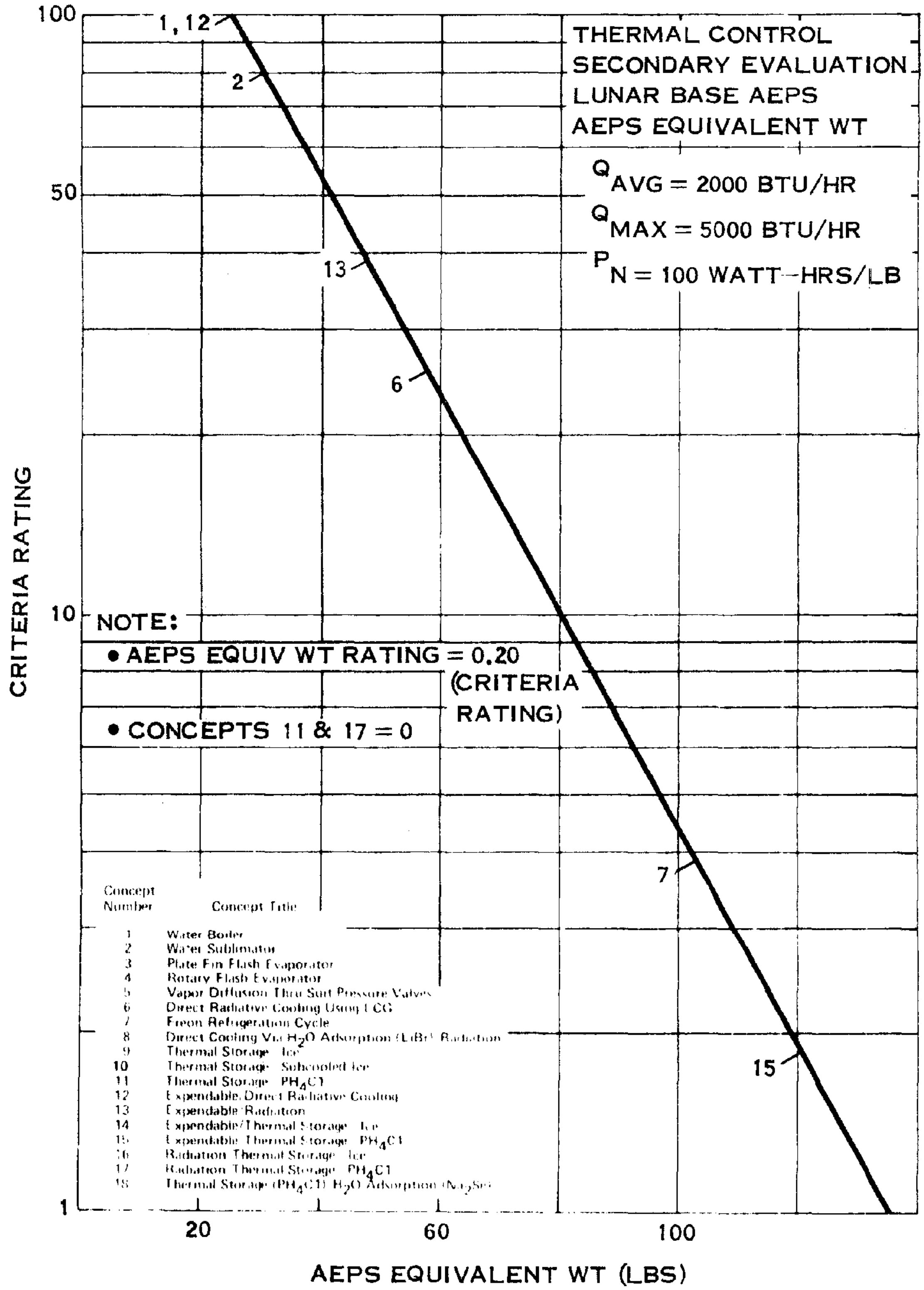
THERMAL CONTROL
SECONDARY EVALUATION - SPACE STATION AEPS

SUMMARY

	Criteria					
Concept	Vehicle Volume	AEPS Weight	Interface Compatibility	Maintainability	Cost	Total
1	3.0	15.0	25.0	20.0	10.0	73.0
2	3.0	9.8	25.0	20.0	10.0	67.8
11	30.0	0	20.7	20.0	1.5	72.2
13	30.0	2.1	13.6	7.0	6.5	59.2
15	20.0	0.3	23.0	20.0	1.0	64.3

LUNAR BASE


6, 11, 17
7
12, 15
13
1, 2
100
50
10
1
CRITERIA RATING
20
60
100
VEHICLE EQUIVALENT VOL (FT^3)
THERMAL CONTROL
SECONDARY EVALUATION
LUNAR BASE AEPS
VEHICLE EQUIVALENT VOL
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
T = 8 HRS/EVA MISSION
T_{TOTAL} = 1440 HRS
VEHICLE EQUIV VOL RATING = 0.30 (CRITERIA RATING)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation/Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2S)



THERMAL CONTROL
SECONDARY EVALUATION
LUNAR BASE AEPS
AEPS EQUIVALENT WT
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
100
50
10
1
1,12
2
13
6
7
15
NOTE:
• AEPS EQUIV WT RATING = 0.20 (CRITERIA RATING)
• CONCEPTS 11 & 17 = 0
CRITERIA RATING
20
60
100
AEPS EQUIVALENT WT (LBS)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Soft Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable/Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2S)

THERMAL CONTROL
SECONDARY EVALUATION - LUNAR BASE AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	50	20	90	20.0
2	20	50	20	90	20.0
6	15	10	30	55	12.2
7	15	10	30	55	12.2
11	20	25	30	75	16.7
12	15	10	20	45	10.0
13	20	10	20	50	11.1
15	20	40	20	80	17.8
17	20	10	25	55	12.2

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (20) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

THERMAL CONTROL
SECONDARY EVALUATION - LUNAR BASE AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
2	40	20	40	100	20.0
6	15	10	10	35	7.0
7	15	10	5	30	6.0
11	40	20	40	100	20.0
12	15	10	10	35	7.0
13	15	10	5	30	6.0
15	40	20	40	100	20.0
17	15	10	5	30	6.0

Notes:

A = Complexity of Maintenance (40 points)
B = Average Downtime (20 points)
C = Frequency of Downtimes (40 points)

$$\text{Maintainability Rating} \quad \frac{\text{total}}{100} \quad (20) \quad (\text{Normalizing Factor})^{*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

THERMAL CONTROL
SECONDARY EVALUATION - LUNAR BASE AEPS

COST

Concept	A	B	Total	Rating
1	30	70	100	10.0
2	30	70	100	10.0
6	20	60	80	8.0
7	15	50	65	6.5
11	15	0	15	1.5
12	20	60	80	8.0
13	15	60	75	7.5
15	10	0	10	1.0
17	10	0	10	1.0

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

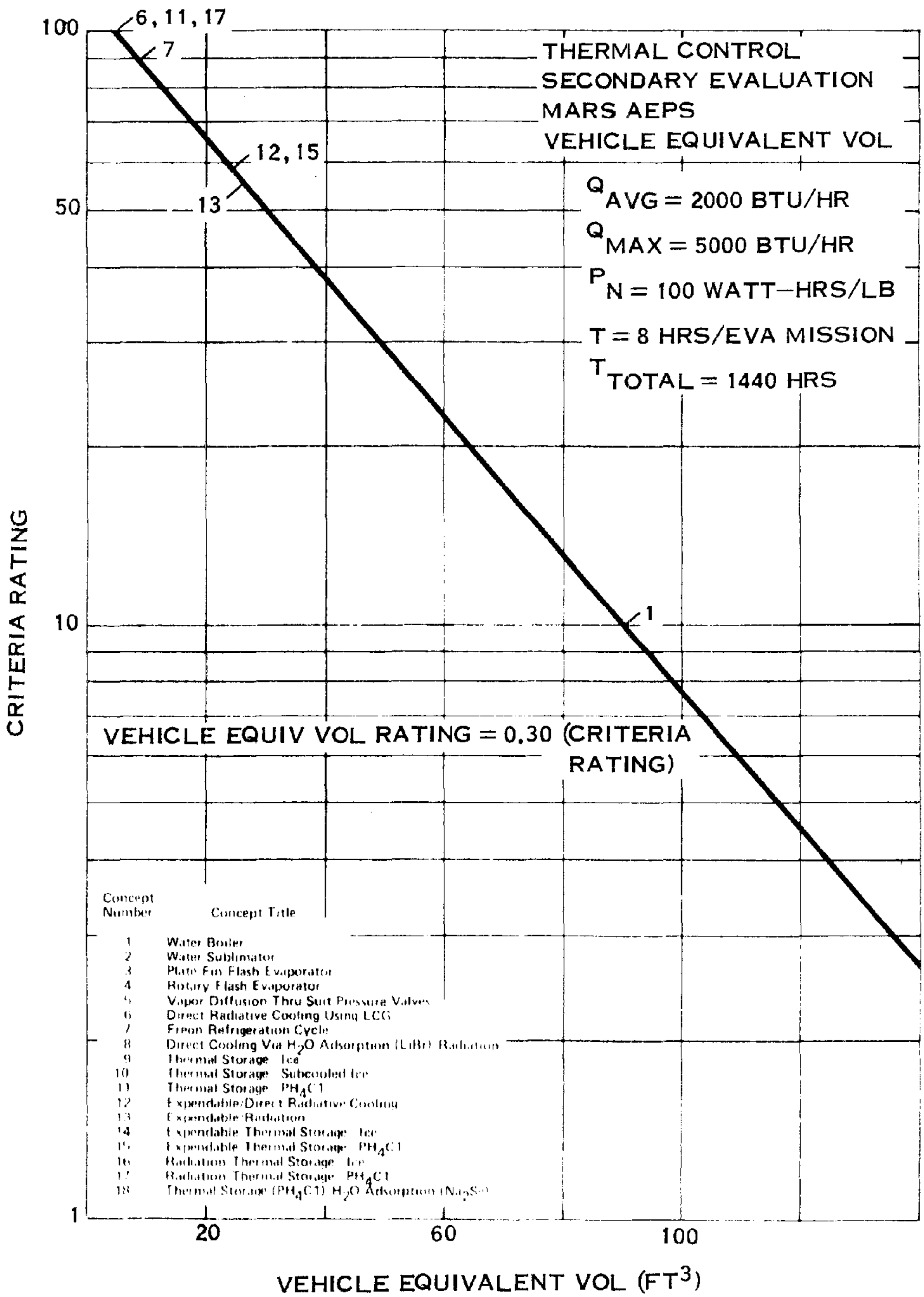
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

THERMAL CONTROL
SECONDARY EVALUATION - LUNAR BASE AEPS

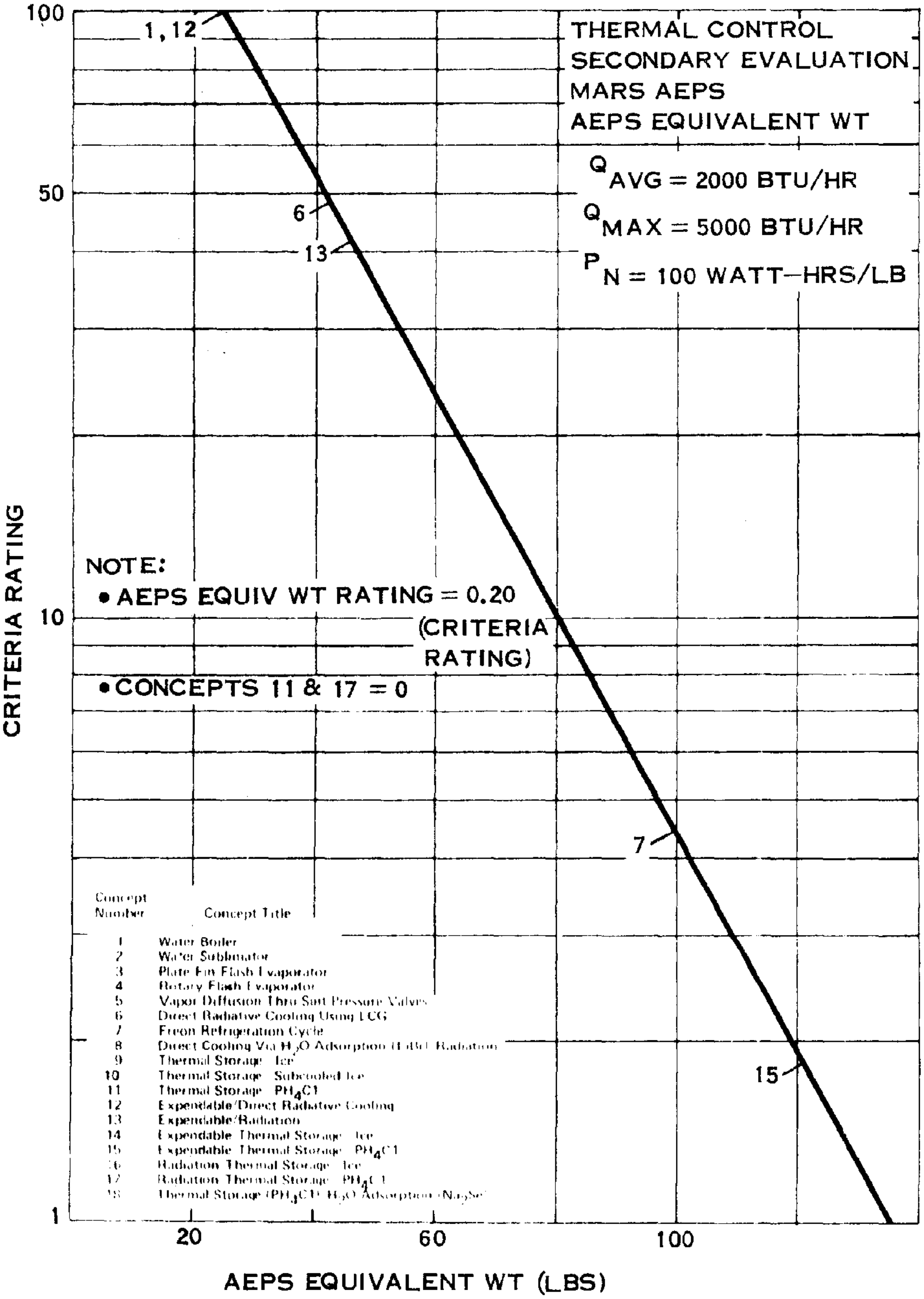
SUMMARY

Concept	Criteria: Vehicle Volume	AEPS Weight	Interface Compatibility	Maintainability	Cost	Total
1	3.0	20.0	20.0	20.0	10.0	73.0
2	3.0	16.0	20.0	20.0	10.0	69.0
6	30.0	5.0	12.2	7.0	8.0	62.2
7	27.0	0.8	12.2	6.0	6.5	52.5
11	30.0	0	16.7	20.0	1.5	68.2
12	18.0	20.0	10.0	7.0	8.0	63.0
13	16.5	7.6	11.1	6.0	7.5	49.2
15	18.0	0.4	17.8	20.0	1.0	57.2
17	30.0	0	12.2	6.0	1.0	49.2

MARS



THERMAL CONTROL
SECONDARY EVALUATION
MARS AEPS
VEHICLE EQUIVALENT VOL
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
T = 8 HRS/EVA MISSION
T_{TOTAL} = 1440 HRS
VEHICLE EQUIV VOL RATING = 0.30 (CRITERIA RATING)
6, 11, 17
7
12, 15
13
1
100
50
10
1
20
60
100
CRITERIA RATING
VEHICLE EQUIVALENT VOL (FT^3)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption (LiBr) Radiation
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage (PH_4C1) H_2O Adsorption (Na_2S)



THERMAL CONTROL
SECONDARY EVALUATION
MARS AEPS
AEPS EQUIVALENT WT
Q_{AVG} = 2000 BTU/HR
Q_{MAX} = 5000 BTU/HR
P_N = 100 WATT–HRS/LB
NOTE:
• AEPS EQUIV WT RATING = 0.20 (CRITERIA RATING)
• CONCEPTS 11 & 17 = 0
1,12
6
13
7
15
100
50
10
1
20
60
100
CRITERIA RATING
AEPS EQUIVALENT WT (LBS)
Concept Number
Concept Title
1 Water Boiler
2 Water Sublimator
3 Plate Fin Flash Evaporator
4 Rotary Flash Evaporator
5 Vapor Diffusion Thru Suit Pressure Valves
6 Direct Radiative Cooling Using LCG
7 Freon Refrigeration Cycle
8 Direct Cooling Via H_2O Adsorption
9 Thermal Storage Ice
10 Thermal Storage Subcooled Ice
11 Thermal Storage PH_4C1
12 Expendable/Direct Radiative Cooling
13 Expendable/Radiation
14 Expendable Thermal Storage Ice
15 Expendable Thermal Storage PH_4C1
16 Radiation Thermal Storage Ice
17 Radiation Thermal Storage PH_4C1
18 Thermal Storage

THERMAL CONTROL
SECONDARY EVALUATION - MARS AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	50	20	90	20.0
6	15	10	30	55	12.2
7	15	10	30	55	12.2
11	20	25	30	75	16.7
12	15	10	20	45	10.0
13	20	10	20	50	11.1
15	20	40	20	80	17.8
17	20	10	25	55	12.2

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (20) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

THERMAL CONTROL
SECONDARY EVALUATION - MARS AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
6	40	20	40	100	20.0
7	15	10	10	35	7.0
11	40	20	40	100	6.0
12	15	10	10	30	7.0
13	15	10	5	30	6.0
15	40	20	40	100	20.0
17	15	10	5	30	6.0

Notes:

A = Complexity of Maintenance (40 points)
B = Average Downtime (20 points)
C = Frequency of Downtimes (40 points)

$$\text{Maintainability Rating} = \frac{\text{total}}{100} \text{ (20) (Normalizing Factor)}^{*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

THERMAL CONTROL
SECONDARY EVALUATION - MARS AEPS

COST

Concept	A	B	Total	Rating
1	30	70	100	10.0
6	20	60	80	8.0
7	15	50	65	6.5
11	15	0	15	1.5
12	20	60	80	8.0
13	15	60	75	7.5
15	10	0	10	1.0
17	10	0	10	1.0

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

THERMAL CONTROL
SECONDARY EVALUATION - MARS AEPS

SUMMARY

	Criteria					
Concept	Vehicle Volume	AEPS Weight	Interface Compatibility	Maintainability	Cost	Total
1	3.0	20.0	20.0	20.0	10.0	73.0
6	30.0	9.4	12.2	7.0	8.0	66.6
7	27.0	0.9	12.2	6.0	6.5	52.6
11	30.0	0	16.7	20.0	1.5	68.2
12	18.0	20.0	10.0	7.0	8.0	63.0
13	16.5	8.0	11.1	6.0	7.5	49.2
15	18.0	0.4	17.8	20.0	1.0	57.2
17	30.0	0	12.2	6.0	1.0	49.2

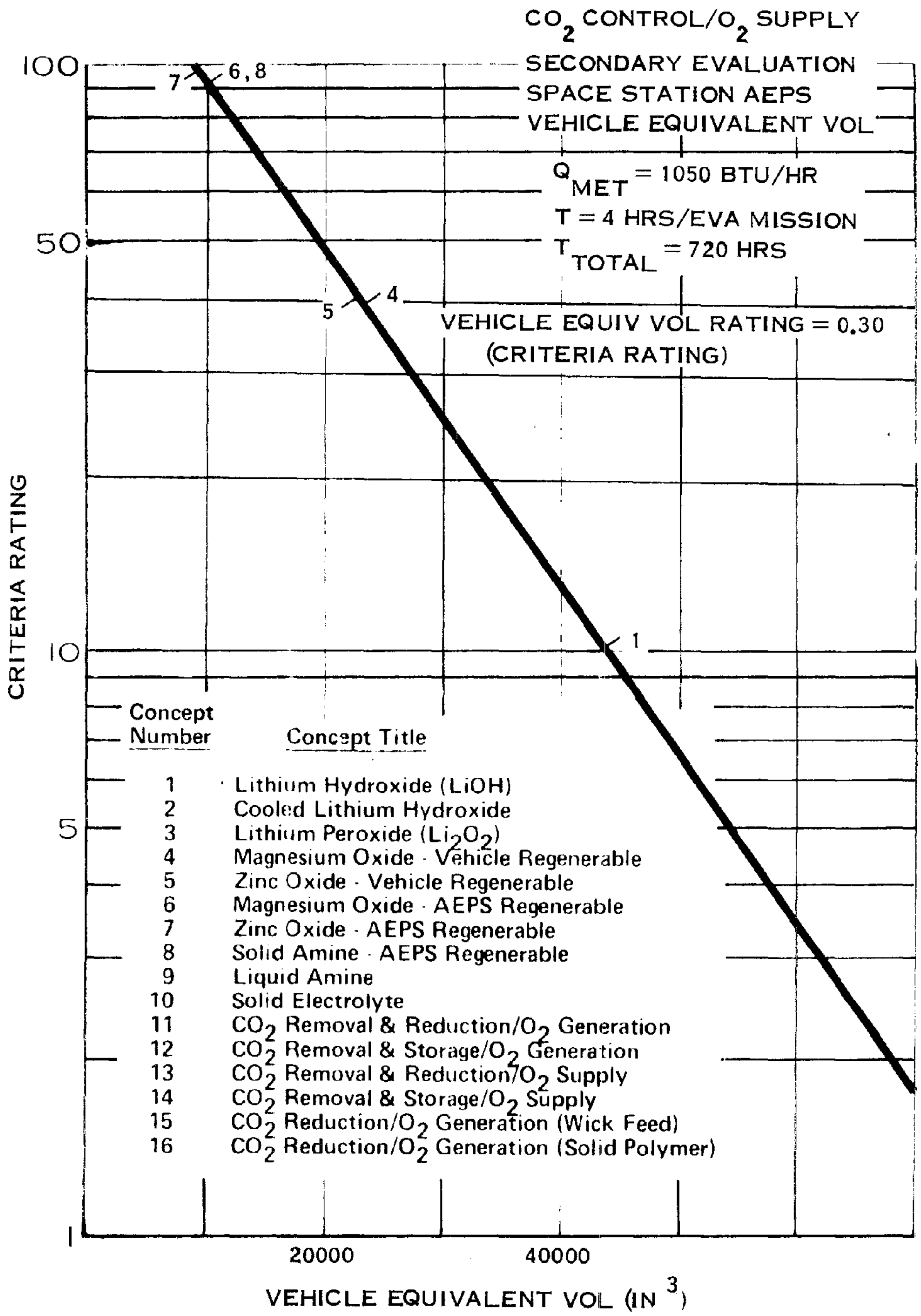
5.1.2.3 CO_2 Control/O_2 Supply - Six (6) CO_2 control/O_2 supply concepts passed the primary evaluation and were carried into the secondary evaluation. All six of these concepts were considered for Space Station and Lunar Base; however, only Lithium Hydroxide (LiOH) and the two vehicle regenerable metallic oxide concepts were considered for Mars.

The following five (5) concepts passed the secondary evaluation:

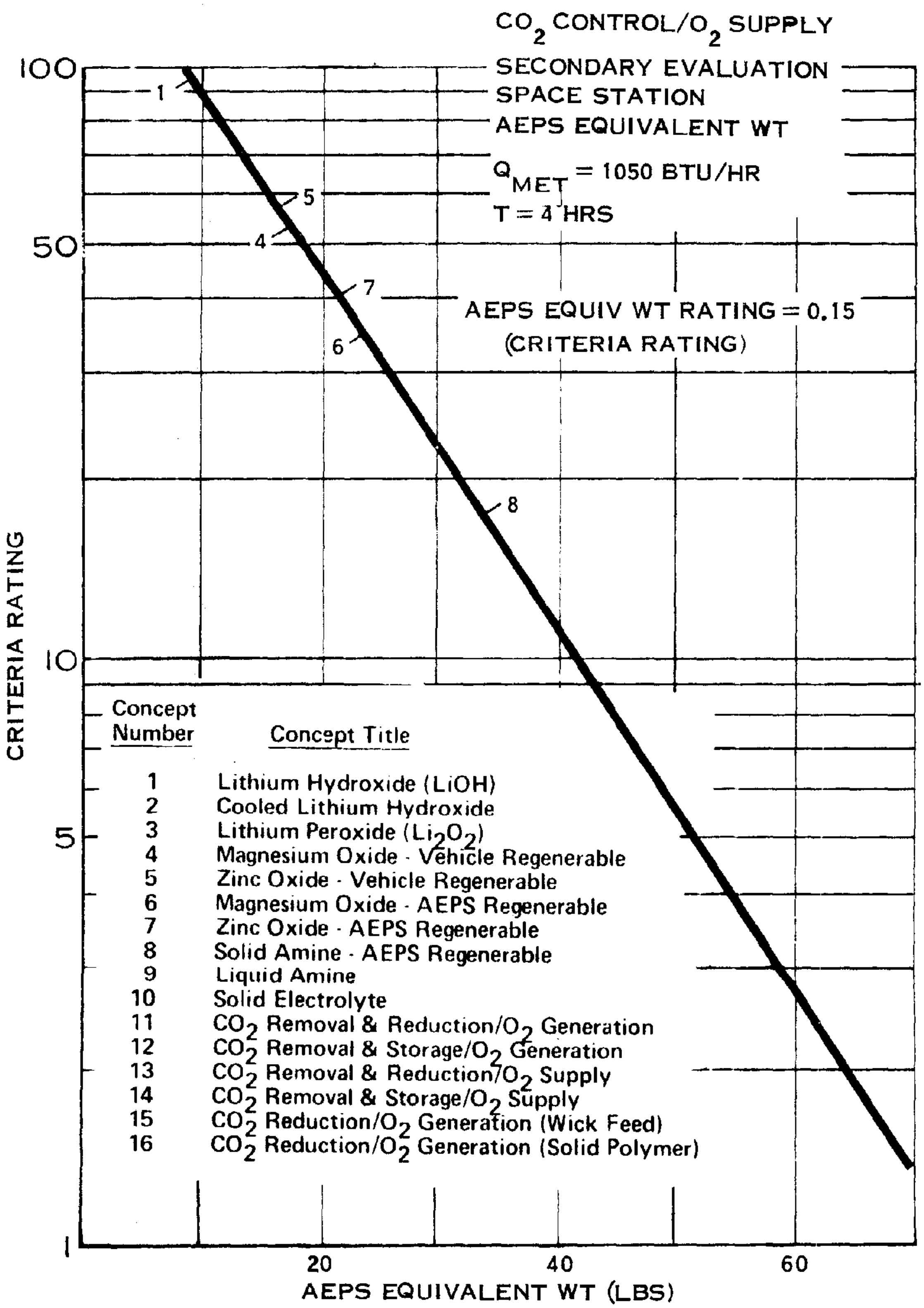
a. Magnesium Oxide - Vehicle Regenerable
b. Zinc Oxide - Vehicle Regenerable
c. Magnesium Oxide - AEPS Regenerable
d. Zinc Oxide - AEPS Regenerable
e. Solid Amine - AEPS Regenerable

Implementation of the secondary evaluation criteria and the resultant candidate CO_2 control/O_2 supply concept ratings are presented in detail on the following pages.

SPACE STATION



CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION
SPACE STATION AEPS
VEHICLE EQUIVALENT VOL
Q_{MET} = 1050 BTU/HR
T = 4 HRS/EVA MISSION
T_{TOTAL} = 720 HRS
VEHICLE EQUIV VOL RATING = 0.30
(CRITERIA RATING)
100
50
10
5
1
7
6,8
5
4
1
CRITERIA RATING
20000
40000
VEHICLE EQUIVALENT VOL (IN^3)
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)


CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION
SPACE STATION
AEPS EQUIVALENT WT
Q_{MET} = 1050 BTU/HR
T = 4 HRS
AEPS EQUIV WT RATING = 0.15
(CRITERIA RATING)
CRITERIA RATING
100
50
10
5
1
AEPS EQUIVALENT WT (LBS)
20
40
60
1
5
4
7
6
8
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - SPACE STATION AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	32	4	56	14.6
4	20	28	20	68	17.7
5	20	28	20	68	17.7
6	12	44	24	80	20.8
7	12	44	24	80	20.8
8	16	52	28	96	25.0

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (25) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - SPACE STATION AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
4	40	20	40	100	20.0
5	40	20	40	100	20.0
6	30	15	35	80	16.0
7	30	15	35	80	16.0
8	35	15	40	90	18.0

Notes:

A Complexity of Maintenance (40 points)
B Average Downtime (20 points)
C Frequency of Downtimes (40 points)

$$\text{Maintainability Rating} \quad \frac{\text{total}}{100} \quad (20) \quad (\text{Normalizing Factor})^{*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - SPACE STATION AEPS

COST

Concept	A	B	Total	Rating
1	0	70	70	10.0
4	20	40	60	8.6
5	20	40	60	8.6
6	20	30	50	7.2
7	20	30	50	7.2
8	30	40	70	10.0

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

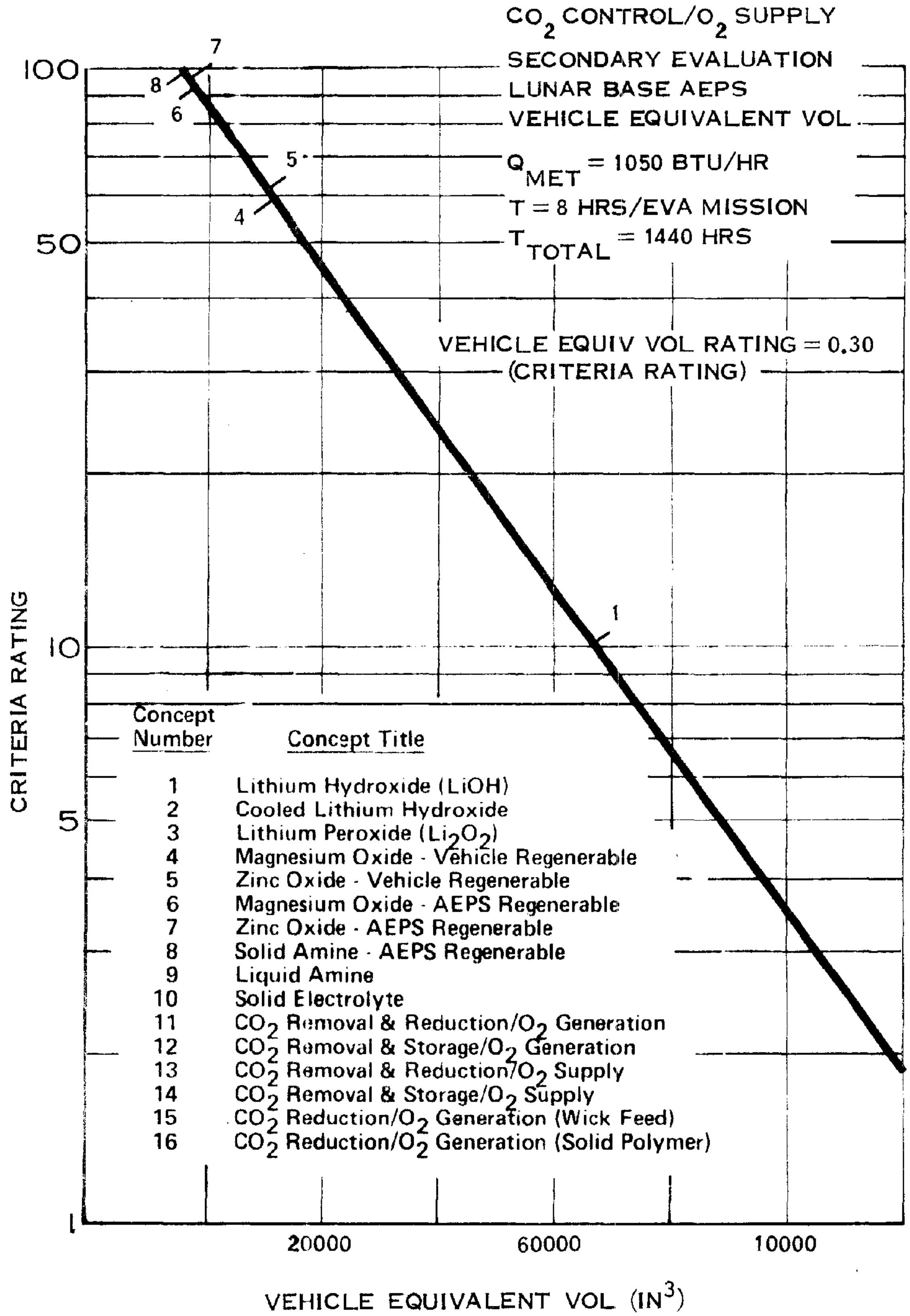
CO_2 CONTROL/O_2 SUPPLY

SECONDARY EVALUATION - SPACE STATION AEPS

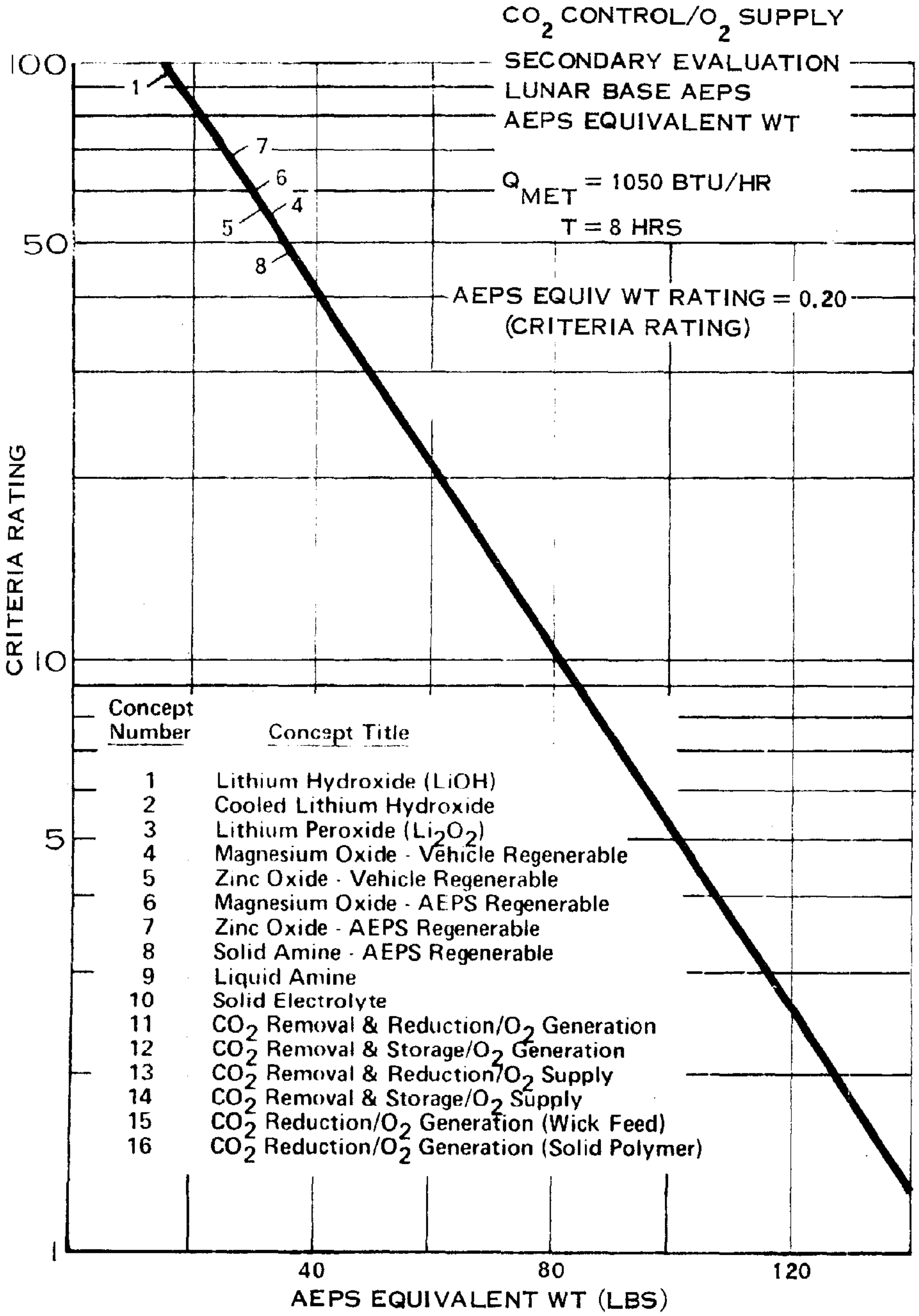
SUMMARY

	Criteria					
Concept	Vehicle Volume	AEPS Weight	Interface Compatibility	Maintainability	Cost	Total
1	3.0	14.5	14.6	20.0	10.0	62.1
4	11.7	8.1	17.7	20.0	8.6	66.1
5	12.0	8.5	17.7	20.0	8.6	66.8
6	28.8	5.2	20.8	16.0	7.2	78.0
7	29.4	6.2	20.8	16.0	7.2	79.6
8	28.8	2.6	25.0	18.0	10.0	84.4

LUNAR BASE



CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION
LUNAR BASE AEPS
VEHICLE EQUIVALENT VOL
Q_{MET} = 1050 BTU/HR
T = 8 HRS/EVA MISSION
T_{TOTAL} = 1440 HRS
VEHICLE EQUIV VOL RATING = 0.30
(CRITERIA RATING)
CRITERIA RATING
100
50
10
5
1
20000
60000
10000
VEHICLE EQUIVALENT VOL (IN^3)
7
8
6
5
4
1
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)


CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION
LUNAR BASE AEPS
AEPS EQUIVALENT WT
Q_{MET} = 1050 BTU/HR
T = 8 HRS
AEPS EQUIV WT RATING = 0.20
(CRITERIA RATING)
CRITERIA RATING
100
50
10
5
1
40
80
120
AEPS EQUIVALENT WT (LBS)
1
7
6
4
5
8
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li_2O_2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO_2 Removal & Reduction/O_2 Generation
12 CO_2 Removal & Storage/O_2 Generation
13 CO_2 Removal & Reduction/O_2 Supply
14 CO_2 Removal & Storage/O_2 Supply
15 CO_2 Reduction/O_2 Generation (Wick Feed)
16 CO_2 Reduction/O_2 Generation (Solid Polymer)

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - LUNAR BASE AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	40	5	65	13.7
4	20	35	15	70	14.7
5	20	35	15	70	14.7
6	10	45	25	80	16.9
7	10	45	25	80	16.9
8	15	50	30	95	20.0

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (20) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - LUNAR BASE AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
4	40	20	40	100	20.0
5	40	20	40	100	20.0
6	30	15	35	80	16.0
7	30	15	35	80	16.0
8	35	15	40	90	18.0

Notes:

A Complexity of Maintenance (40 points)
B Average Downtime (20 points)
C Frequency of Downtimes (40 points)

$$\text{Maintaintability Rating} = \frac{\text{total}}{100} (20) \quad \text{(Normalizing Factor)}^*$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - LUNAR BASE AEPS

COST

Concept	A	B	Total	Rating
1	0	70	70	10.0
4	20	40	60	8.6
5	20	40	60	8.6
6	20	30	50	7.2
7	20	30	50	7.2
8	30	40	70	10.0

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

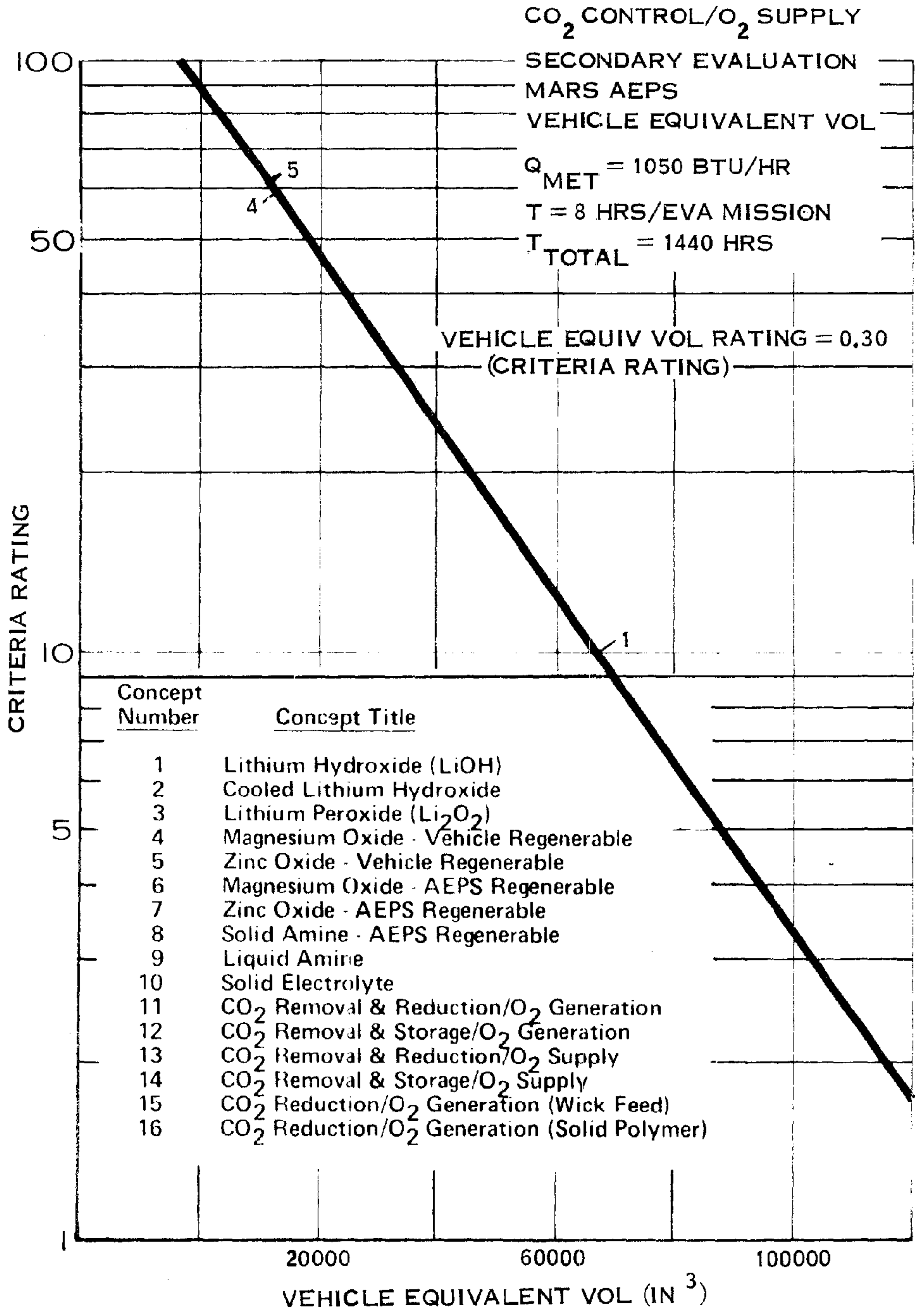
*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - LUNAR BASE AEPS

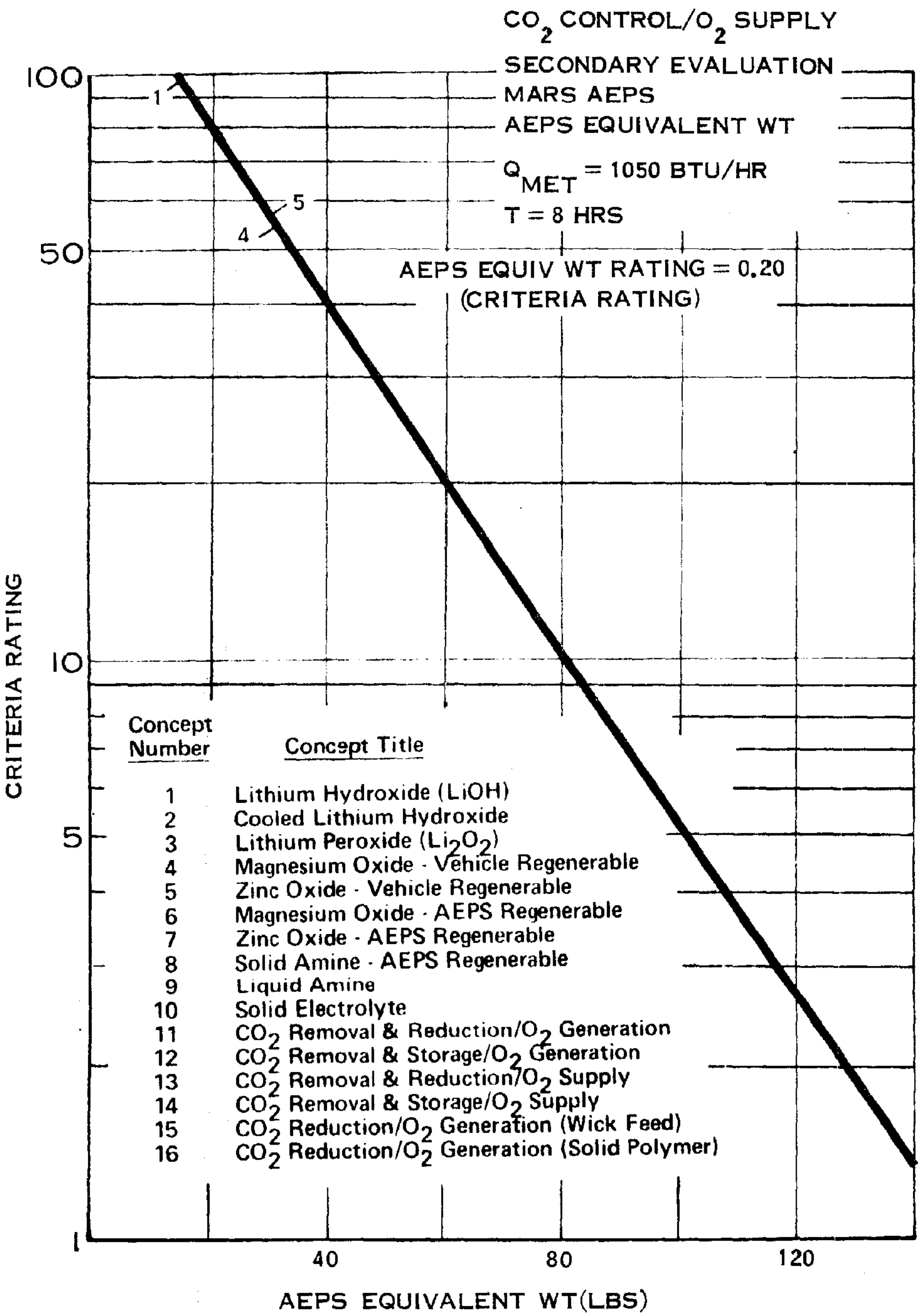
SUMMARY

	Criteria					
Concept	Vehicle Volume	AEPS Weight	Interface Compatibility	Maintainability	Cost	Total
1	3.0	19.4	13.7	20.0	10.0	66.1
4	17.7	11.2	14.7	20.0	8.6	72.2
5	18.6	11.4	14.7	20.0	8.6	73.3
6	27.9	12.0	16.9	16.0	7.2	80.0
7	29.1	13.8	16.9	16.0	7.2	82.9
8	28.2	9.8	20.0	18.0	10.0	86.0

MARS



Concept Number	Concept Title
1	Lithium Hydroxide (LiOH)
2	Cooled Lithium Hydroxide
3	Lithium Peroxide (Li_2O_2)
4	Magnesium Oxide - Vehicle Regenerable
5	Zinc Oxide - Vehicle Regenerable
6	Magnesium Oxide - AEPS Regenerable
7	Zinc Oxide - AEPS Regenerable
8	Solid Amine - AEPS Regenerable
9	Liquid Amine
10	Solid Electrolyte
11	CO_2 Removal & Reduction/O_2 Generation
12	CO_2 Removal & Storage/O_2 Generation
13	CO_2 Removal & Reduction/O_2 Supply
14	CO_2 Removal & Storage/O_2 Supply
15	CO_2 Reduction/O_2 Generation (Wick Feed)
16	CO_2 Reduction/O_2 Generation (Solid Polymer)


CO2 CONTROL/O2 SUPPLY
SECONDARY EVALUATION
MARS AEPS
AEPS EQUIVALENT WT
QMET = 1050 BTU/HR
T = 8 HRS
AEPS EQUIV WT RATING = 0.20
(CRITERIA RATING)
100
50
10
5
1
1
5
4
CRITERIA RATING
40
80
120
AEPS EQUIVALENT WT(LBS)
Concept Number
Concept Title
1 Lithium Hydroxide (LiOH)
2 Cooled Lithium Hydroxide
3 Lithium Peroxide (Li2O2)
4 Magnesium Oxide - Vehicle Regenerable
5 Zinc Oxide - Vehicle Regenerable
6 Magnesium Oxide - AEPS Regenerable
7 Zinc Oxide - AEPS Regenerable
8 Solid Amine - AEPS Regenerable
9 Liquid Amine
10 Solid Electrolyte
11 CO2 Removal & Reduction/O2 Generation
12 CO2 Removal & Storage/O2 Generation
13 CO2 Removal & Reduction/O2 Supply
14 CO2 Removal & Storage/O2 Supply
15 CO2 Reduction/O2 Generation (Wick Feed)
16 CO2 Reduction/O2 Generation (Solid Polymer)

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - MARS AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	40	5	65	13.7
4	20	35	15	70	14.7
5	20	35	15	70	14.7

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (20) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - MARS AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
4	40	20	40	100	20.0
5	40	20	40	100	20.0

Notes:

A = Complexity of Maintenance (40 points)
B = Average Downtime (20 points)
C = Frequency of Downtimes (40 points)

$$\text{Maintaintability Rating} = \frac{\text{total}}{100} (20) \quad (\text{Normalizing Factor})^{*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

CO_2 CONTROL/O_2 SUPPLY

SECONDARY EVALUATION - MARS AEPS

COST

Concept	A	B	Total	Rating
1	0	70	70	10.0
4	20	40	60	8.6
5	20	40	60	8.6

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

CO_2 CONTROL/O_2 SUPPLY
SECONDARY EVALUATION - MARS AEPS

SUMMARY

	Criteria					
Concept	Vehicle Volume	AEPS Weight	Interface Compatibility	Maintainability	Cost	Total
1	3.0	19.4	13.7	20.0	10.0	66.1
4	17.7	11.2	14.7	20.0	8.6	72.2
5	18.6	11.4	14.7	20.0	8.6	73.3

5.2 Phase Two Effort

5.2.1 Shuttle AEPS

5.2.1.1 Primary Evaluation

All shuttle AEPS candidate subsystem concepts that passed the go/no go evaluation were subjected to a primary evaluation as described in section 5.1.1. The criteria weighting factors were the same as those specified for Space Station in table 5-1.

The primary criteria whose ratings were determined quantitatively are vehicle equivalent weight and AEPS equivalent volume. The competitive ratings for both these criteria were determined by establishing a straight-line relationship between the criteria rating and vehicle equivalent weight or AEPS equivalent volume, as the case may be, on a semi-log scale. The relationships were established for both thermal control and CO_2 control/O_2 supply concepts, on a mission basis, by selecting criteria values that corresponded with a 100 point criteria rating and a 10 point criteria rating in accordance with table 5-7.

TABLE 5-7

SUBSYSTEM	PRIMARY CRITERION	VALUE
Thermal Control	Vehicle Equivalent Weight	
	100 points	50 lbs.
	10 points	216 lbs.
	AEPS Equivalent Volume	
	100 points	0
	10 points	2500 in^3
CO_2 Control/O_2 Supply	Vehicle Equivalent Weight	
	100 points	50 lbs.
	10 points	216 lbs.
	AEPS Equivalent Volume	
	100 points	0
	10 points	2500 in^3

The criteria ratings for the candidate subsystem concepts were then simply determined by selecting the rating corresponding to the concept's vehicle equivalent weight or AEPS equivalent volume as defined by the parametric analysis presented in section 4.0. A semi-log scale was utilized to provide added benefit to those concepts that exhibited low vehicle weights and AEPS equivalent volumes and to penalize those concepts with high vehicle equivalent weights and AEPS equivalent volumes.

5.2.1.1.1 Thermal Control - Table 5-8 is an index of the seven (7) candidate thermal control concepts that passed the go/no go evaluation and were carried into the primary evaluation.

TABLE 5-8

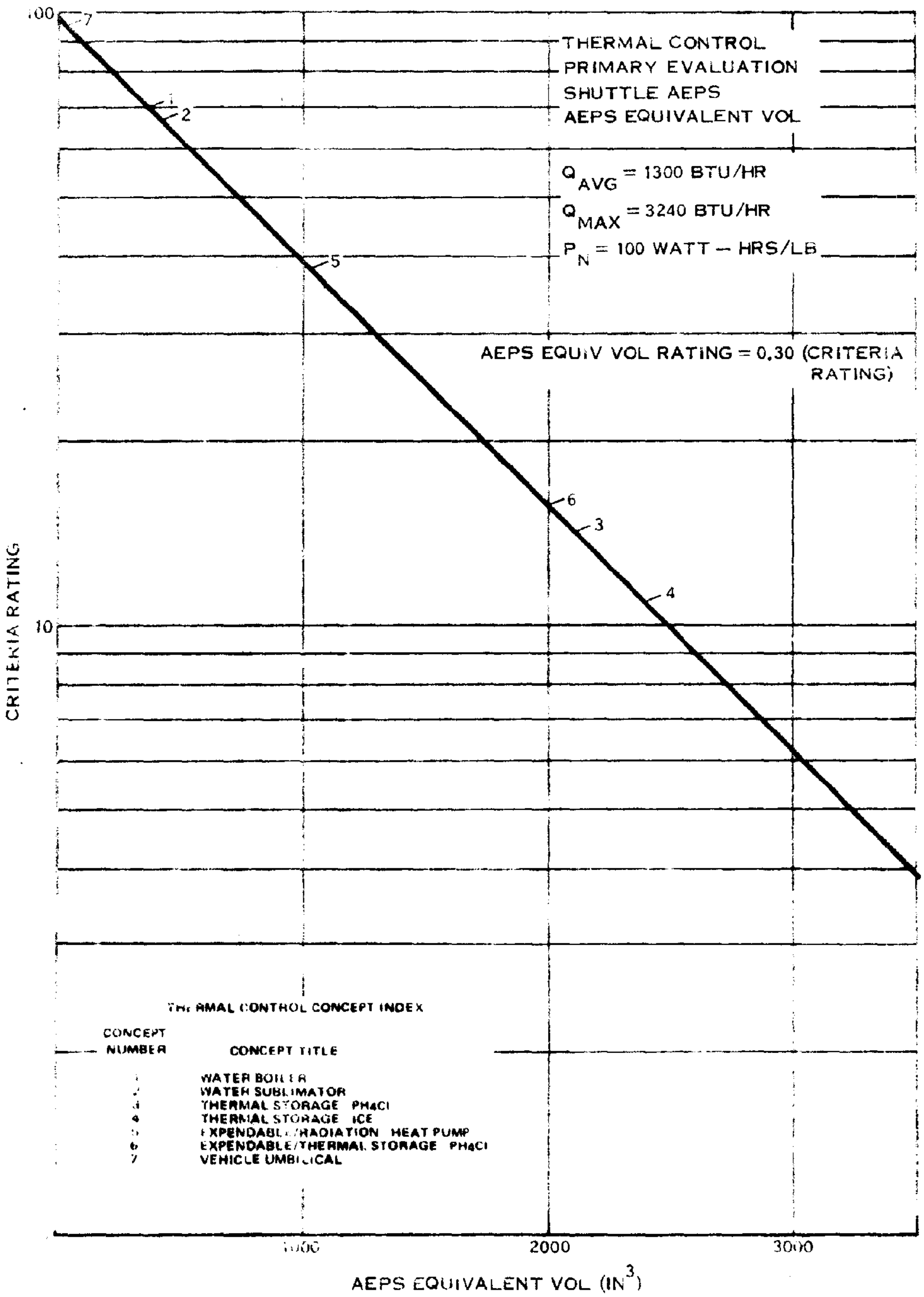
THERMAL CONTROL CONCEPT INDEX

CONCEPT NUMBER	CONCEPT TITLE
1	Water Boiler
2	Water Sublimator
3	Thermal Storage - PH_4Cl
4	Thermal Storage - ICE
5	Expendable/Radiation - Heat Pump
6	Expendable/Thermal Storage - PH_4Cl
7	Vehicle Umbilical

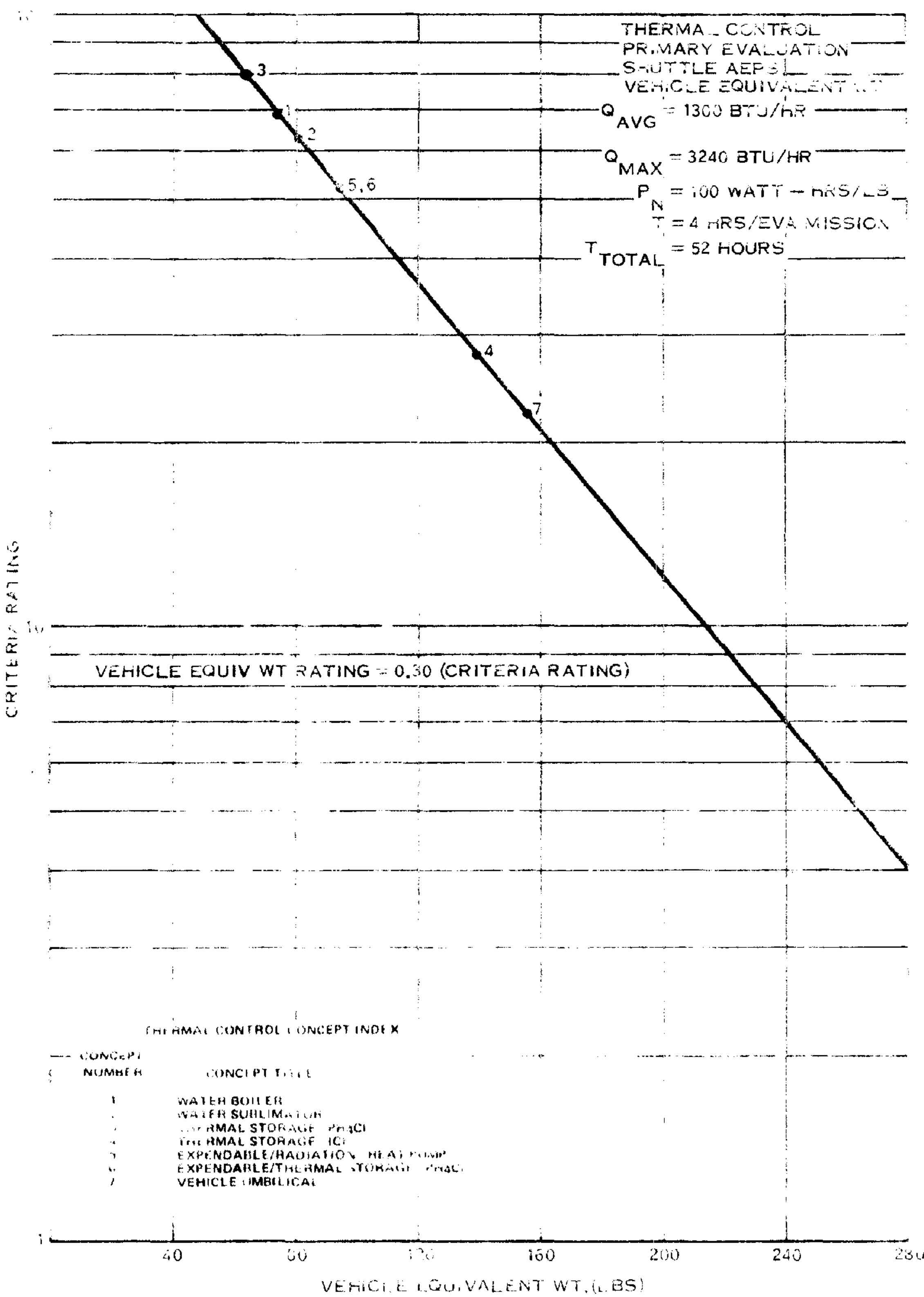
The following two (2) concepts passed the primary evaluation and were carried into the secondary evaluation:

a. Water Boiler
b. Water Sublimator

Implementation of the primary evaluation criteria and the resultant candidate thermal control concept ratings are presented in detail on the following pages.



THERMAL CONTROL
PRIMARY EVALUATION
SHUTTLE AEPS
AEPS EQUIVALENT VOL
Q_{AVG} = 1300 BTU/HR
Q_{MAX} = 3240 BTU/HR
P_N = 100 WATT – HRS/LB
AEPS EQUIV VOL RATING = 0.30 (CRITERIA RATING)
100
10
CRITERIA RATING
1
2
3
4
5
6
7
1000
2000
3000
AEPS EQUIVALENT VOL (IN^3)
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 THERMAL STORAGE PH4Cl
4 THERMAL STORAGE ICE
5 EXPENDABLE/RADIATION HEAT PUMP
6 EXPENDABLE/THERMAL STORAGE PH4Cl
7 VEHICLE UMBILICAL



THERMAL CONTROL
PRIMARY EVALUATION
SHUTTLE AEPS
VEHICLE EQUIVALENT WT
Q_{AVG} = 1300 BTU/HR
Q_{MAX} = 3240 BTU/HR
P_N = 100 WATT – HRS/LB
T = 4 HRS/EVA MISSION
T_{TOTAL} = 52 HOURS
3
1
2
5,6
4
7
VEHICLE EQUIV WT RATING = 0.30 (CRITERIA RATING)
CRITERIA RATING
10
1
40
80
160
200
240
280
VEHICLE EQUIVALENT WT, (LBS)
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
WATER SUBLIMATOR
THERMAL STORAGE
THERMAL STORAGE
EXPENDABLE/RADIATION
EXPENDABLE/THERMAL STORAGE
7 VEHICLE UMBILICAL

PRIMARY EVALUATION - SHUTTLE AEPS

RELIABILITY

Concept	Rating
1	13.6
2	15.0
3	11.0
4	6.8
5	13.4
6	10.0
7	15.0

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of sybsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

PRIMARY EVALUATION - SHUTTLE AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	4	14	10	5	25	25	98	15.0
2	15	4	14	10	4	25	25	97	14.9
3	14	5	13	2	5	25	20	84	12.9
4	13	3.5	10	2	3	7	15	53.5	8.2
5	5	4	12	2	5	25	20	73	11.2
6	15	4	12	10	5	25	20	91	13.9
7	15	5	15	0	5	25	0	65	9.9

Notes:

A - Don/doff (15 points)
B - Startup (5 points)
C - Checkout (15 points)
D - Egress/ingress (10 points)
E - Shutdown (5 points)
F - Recharge/regeneration (25 points)
G - Operational variations during EVA (25 points)

$$\text{Operability Rating} = \frac{\text{total}}{100} (15) \text{ (Normalizing Factor)*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

PRIMARY EVALUATION - SHUTTLE AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	16	0	66	6.6
3	40	25	25	90	9.0
4	30	25	0	55	5.5
5	45	20	20	85	8.5
6	50	25	25	100	10.0
7	10	4	0	14	1.4

Notes:

A = EVA mission flexibility (50 points)
B = Applicability to different space programs (25 points)
C = Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100} \text{ (10) (Normalizing Factor)*}$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

PRIMARY EVALUATION - SHUTTLE AEPS

SUMMARY

Concept	Criteria: AEPS Vol.	Vehicle Wt.	Reliability	Operability	Flexibility	Total
1	22.0	26.0	13.6	15.0	7.5	84.1
2	21.0	24.0	15.0	14.9	6.6	81.5
3	4.4	30.0	11.0	12.9	9.0	67.3
4	3.5	10.8	6.8	8.2	5.5	34.8
5	12.0	20.0	13.4	11.2	8.5	65.1
6	4.9	20.0	10.0	13.9	10.0	58.8
7	30.0	8.8	15.0	9.9	1.4	65.1

5.2.1.1.2 CO_2 Control/O_2 Supply - Table 5-9 is an index of the eleven (11) candidate CO_2 control/O_2 supply subsystem concepts that passed the go/no go evaluation and were carried into the primary evaluation.

TABLE 5-9

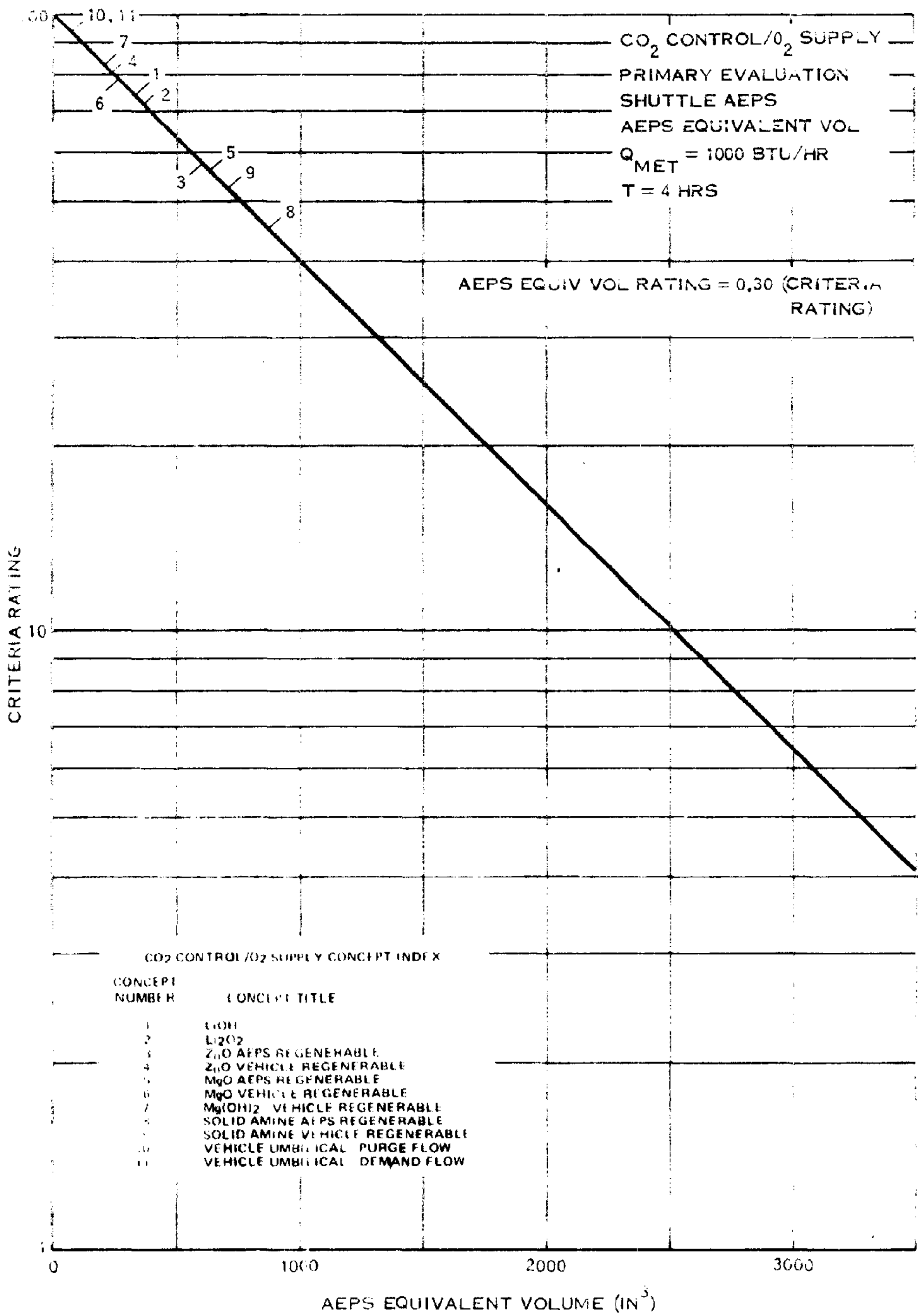
CO_2 CONTROL/O_2 SUPPLY CONCEPT INDEX

Concept Number	Concept Title
1	LiOH
2	Li_2O_2
3	ZnO-AEPS regenerable
4	ZnO-Vehicle regenerable
5	MgO-AEPS regenerable
6	MgO-Vehicle regenerable
7	$Mg(OH)_2$-Vehicle regenerable
8	Solid Amine-AEPS regenerable
9	Solid Amine-Vehicle regenerable
10	Vehicle Umbilical - Purge flow
11	Vehicle Umbilical - Demand flow

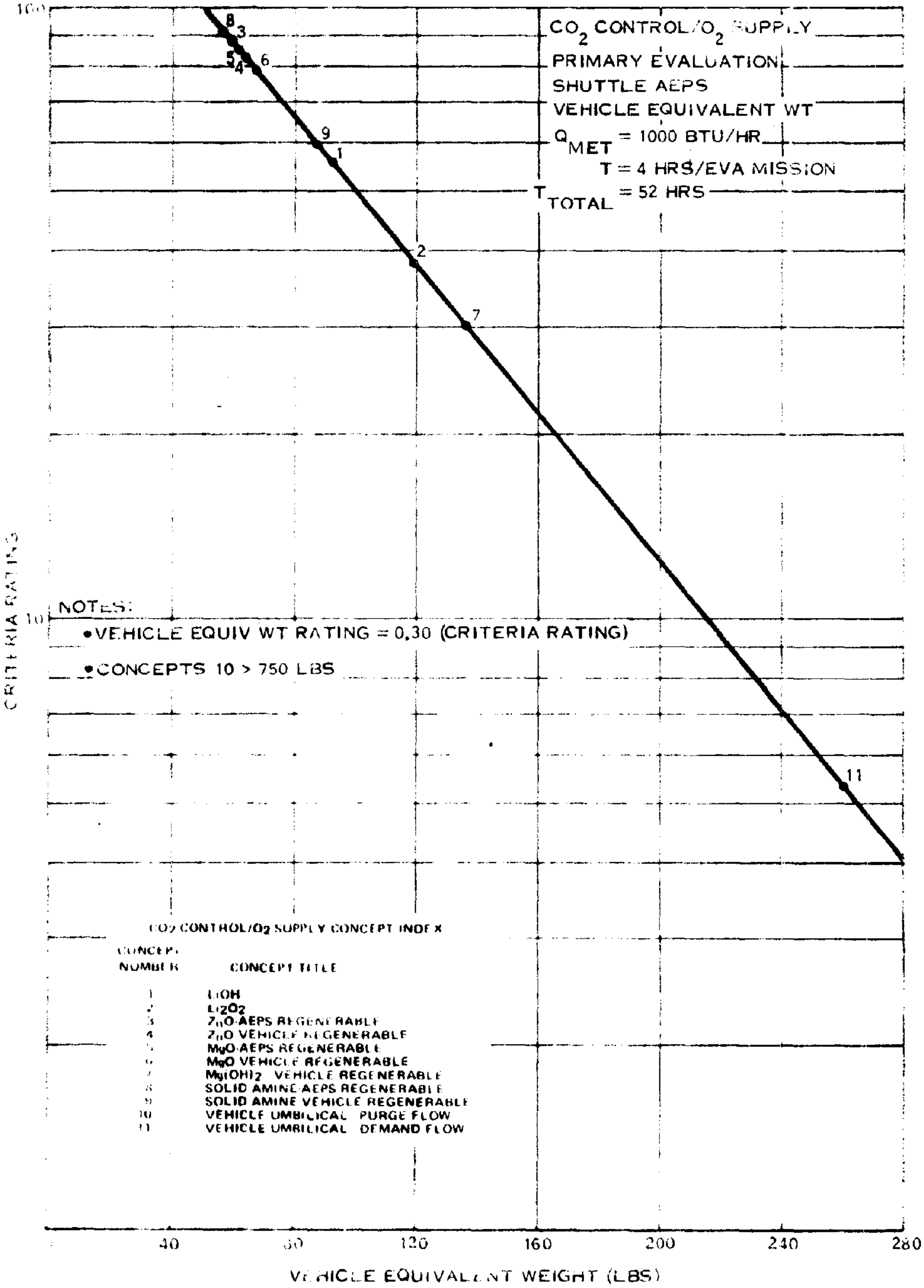
The following six (6) concepts passed the primary evaluation and were carried into the secondary evaluation:

a. LiOH
b. ZnO-AEPS regenerable
c. ZnO-Vehicle regenerable
d. MgO-AEPS regenerable
e. MgO-Vehicle regeneragle
f. Solid Amine-AEPS regenerable

Implementation of the primary evaluation criteria and the resultant candidate CO_2 control/O_2 supply subsystem concept ratings are presented in detail on the following pages.



CO2 CONTROL/O2 SUPPLY
PRIMARY EVALUATION
SHUTTLE AEPS
AEPS EQUIVALENT VOL
QMET = 1000 BTU/HR
T = 4 HRS
AEPS EQUIV VOL RATING = 0.30 (CRITERIA RATING)
10, 11
7
4
1
2
6
5
3
9
8
CRITERIA RATING
10
1
0
1000
2000
3000
AEPS EQUIVALENT VOLUME (IN3)
CO2 CONTROL/O2 SUPPLY CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 LiOH
2 Li2O2
3 ZnO AEPS REGENERABLE
4 ZnO VEHICLE REGENERABLE
5 MgO AEPS REGENERABLE
6 MgO VEHICLE REGENERABLE
7 Mg(OH)2 VEHICLE REGENERABLE
8 SOLID AMINE AEPS REGENERABLE
9 SOLID AMINE VEHICLE REGENERABLE
10 VEHICLE UMBILICAL PURGE FLOW
11 VEHICLE UMBILICAL DEMAND FLOW



CO2 CONTROL/O2 SUPPLY
PRIMARY EVALUATION
SHUTTLE AEPS
VEHICLE EQUIVALENT WT
QMET = 1000 BTU/HR
T = 4 HRS/EVA MISSION
TTOTAL = 52 HRS
NOTES:
• VEHICLE EQUIV WT RATING = 0.30 (CRITERIA RATING)
• CONCEPTS 10 > 750 LBS
CO2 CONTROL/O2 SUPPLY CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 LiOH
2 Li2O2
3 ZnO-AEPS REGENERABLE
4 ZnO VEHICLE REGENERABLE
5 MgO-AEPS REGENERABLE
6 MgO VEHICLE REGENERABLE
7 Mg(OH)2 VEHICLE REGENERABLE
8 SOLID AMINE-AEPS REGENERABLE
9 SOLID AMINE VEHICLE REGENERABLE
10 VEHICLE UMBILICAL PURGE FLOW
11 VEHICLE UMBILICAL DEMAND FLOW
CRITERIA RATING
100
10
40
80
120
160
200
240
280
VEHICLE EQUIVALENT WEIGHT (LBS)

PRIMARY EVALUATION - SHUTTLE AEPS

RELIABILITY

Concept	Rating
1	15.0
2	12.0
3	7.2
4	10.7
5	7.2
6	10.7
7	10.7
8	9.5
9	10.7
10	15.0
11	15.0

Note:

The reliability rating is a comparative assessment of candidate concepts and is based upon total number of subsystem components and the number of subsystem component failures that could cause mission abort and/or loss of life.

PRIMARY EVALUATION - SHUTTLE AEPS

OPERABILITY

Concept	A	B	C	D	E	F	G	Total	Rating
1	15	5	15	10	5	10	25	85	13.0
2	15	2	10	10	3	5	20	65	10.0
3	15	5	10	10	5	20	25	90	13.8
4	15	5	13	10	5	10	25	83	12.7
5	15	5	10	10	5	20	25	90	13.8
6	15	5	13	10	5	10	25	83	12.7
7	15	5	13	10	5	5	25	78	11.9
8	15	5	13	10	5	25	25	98	15.0
9	15	5	13	10	5	15	25	88	13.5
10	10	5	15	0	5	25	25	85	13.0
11	10	5	15	0	5	25	25	85	13.0

Notes:

A = Don/doff (15 points)
B = Startup (5 points)
C = Checkout (15 points)
D = Egress/ingress (10 points)
E = Shutdown (5 points)
F = Recharge/regeneration (25 points)
G = Operational variations during EVA (25 points)

$$\text{Operability Rating} = \frac{\text{total}}{100}\ (15)\ (\text{Normalizing Factor})^{*}$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 15 points.

PRIMARY EVALUATION - SHUTTLE AEPS

FLEXIBILITY

Concept	A	B	C	Total	Rating
1	50	25	0	75	7.5
2	50	25	15	90	9.0
3	50	17	25	92	9.2
4	50	25	25	100	10.0
5	50	17	25	92	9.2
6	50	25	25	100	10.0
7	50	25	25	100	10.0
8	50	17	25	92	9.2
9	50	25	25	100	10.0
10	20	0	0	20	2.0
11	20	0	0	20	2.0

Notes:

A - EVA mission flexibility (50 points)
B - Applicability to different space programs (25 points)
C - Ability to incorporate new technology (25 points)

$$\text{Flexibility Rating} = \frac{\text{total}}{100}\ (10)\ (\text{Normalizing Factor})^*$$

* Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

PRIMARY EVALUATION - SHUTTLE AEPS

SUMMARY

Concept	Criteria: AEPS Vol.	Vehicle Wt.	Reliability	Operability	Flexibility	Total
1	23.9	18.5	15.0	13.0	7.5	77.9
2	23.2	12.5	12.0	10.0	9.0	66.7
3	18.4	29.0	7.2	13.8	9.2	77.6
4	26.2	27.3	10.7	12.7	10.0	86.9
5	18.1	28.0	7.2	13.8	9.2	76.3
6	25.5	26.0	10.7	12.7	10.0	84.9
7	26.8	9.9	10.7	11.9	10.0	69.3
8	14.5	30.0	9.5	15.0	9.2	78.2
9	17.1	19.8	10.7	13.5	10.0	71.1
10	30.0	0	15.0	13.0	2.0	60.0
11	30.0	1.6	15.0	13.0	2.0	61.6

5.2.1.2 Secondary Evaluation

The Shuttle AEPS candidate subsystem concepts that passed the primary evaluation were subjected to a secondary evaluation as described in section 5.1.2. The criteria weighting factors were the same as those specified for Space Station in table 5-5. The relationships between criteria rating and criteria value were established for both thermal control and CO_2 control/O_2 supply concepts by selecting criteria values that correspond with a 100 point criteria rating and a 10 point criteria rating in accordance with table 5-10.

TABLE 5-10

SUBSYSTEM	SECONDARY CRITERION	VALUE
Thermal Control	Vehicle Equivalent Volume	
	100 Points	2000 in^3
	10 Points	7000 in^3
	AEPS Equivalent Weight	
	100 Points	0
	10 Points	40 lbs.
CO_2 Control/O_2 Supply	Vehicle Equivalent Volume	
	100 Points	2000 in^3
	10 Points	9800 in^3
	AEPS Equivalent Weight	
	100 Points	0
	10 Points	40 lbs.

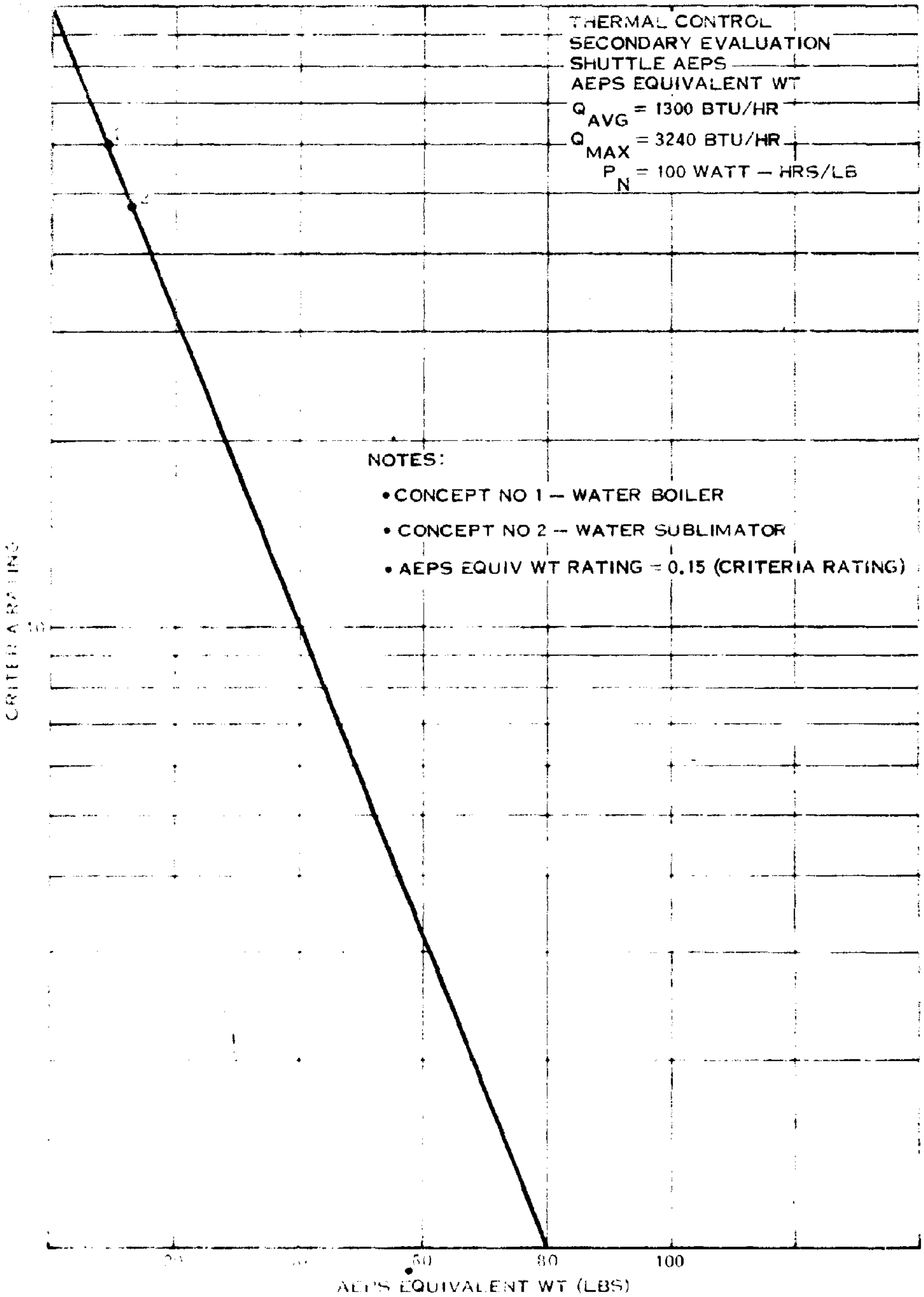
The criteria ratings for the candidate subsystem concepts were then simply determined by selecting the rating corresponding to the concept's vehicle equivalent volume or AEPS equivalent weight as defined by the parametric analysis presented in section 4.0.

5.2.1.2.1 Thermal Control - Two (2) thermal control concepts passed the primary evaluation and were carried into the secondary evaluation:

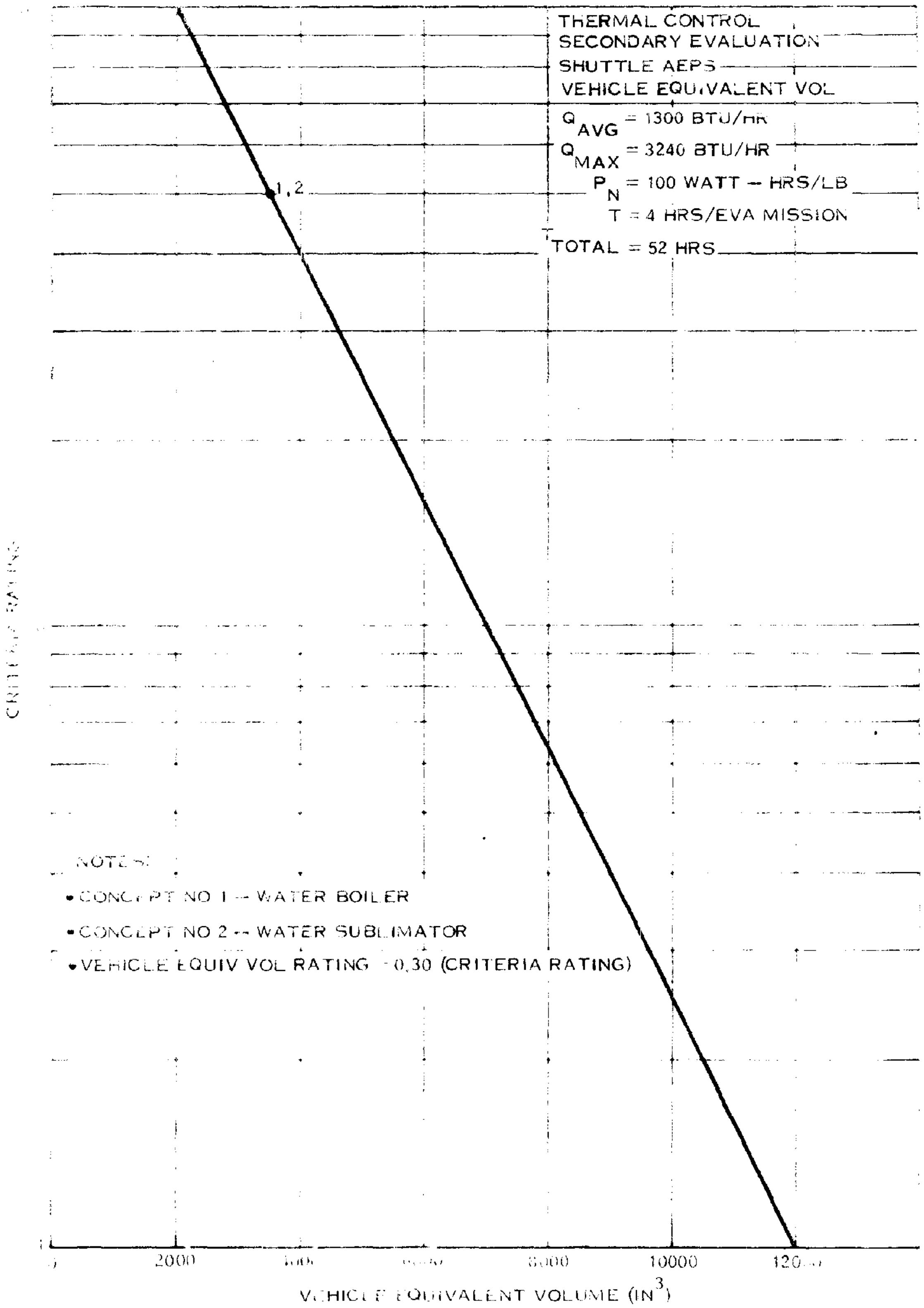
a. Water Boiler
b. Water Sublimator

Both of these concepts passed the secondary evaluation.

Implementation of the secondary evaluation criteria and the resultant thermal control concept ratings are presented in detail on the following pages.



THERMAL CONTROL
SECONDARY EVALUATION
SHUTTLE AEPS
AEPS EQUIVALENT WT
Q_{AVG} = 1300 BTU/HR
Q_{MAX} = 3240 BTU/HR
P_N = 100 WATT – HRS/LB
NOTES:
• CONCEPT NO 1 – WATER BOILER
• CONCEPT NO 2 – WATER SUBLIMATOR
• AEPS EQUIV WT RATING = 0.15 (CRITERIA RATING)
CRITERIA RATING
10
60
80
100
AEPS EQUIVALENT WT (LBS)



THERMAL CONTROL
SECONDARY EVALUATION
SHUTTLE AEPS
VEHICLE EQUIVALENT VOL
Q_{AVG} = 1300 BTU/HR
Q_{MAX} = 3240 BTU/HR
P_N = 100 WATT – HRS/LB
T = 4 HRS/EVA MISSION
TOTAL = 52 HRS
1, 2
NOTES:
• CONCEPT NO 1 – WATER BOILER
• CONCEPT NO 2 – WATER SUBLIMATOR
• VEHICLE EQUIV VOL RATING = 0.30 (CRITERIA RATING)
CRITERIA RATING
2000
8000
10000
VEHICLE EQUIVALENT VOLUME (IN^3)

SECONDARY EVALUATION - SHUTTLE AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	52	20	92	25.0
2	20	52	20	92	25.0

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (52 points)
C = Vehicle Interfaces (28 points)

Interface Compatibility Rating = $\frac{\text{total}}{100}$ (25) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 25 points.

SECONDARY EVALUATION - SHUTTLE AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20.0
2	40	20	40	100	20.0

Notes:

A = Complexity of Maintenance (40 points)
B = Average Downtime (20 points)
C = Frequence of Downtimes (40 points)

Maintainability Rating = $\frac{\text{total}}{100}$ (20) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

SECONDARY EVALUATION - SHUTTLE AEPS

COST

Concept	A	B	Total	Rating
1	30	70	100	10.0
2	30	70	100	10.0

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating = $\frac{\text{total}}{100}$ (10) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

SECONDARY EVALUATION - SHUTTLE AEPS

SUMMARY

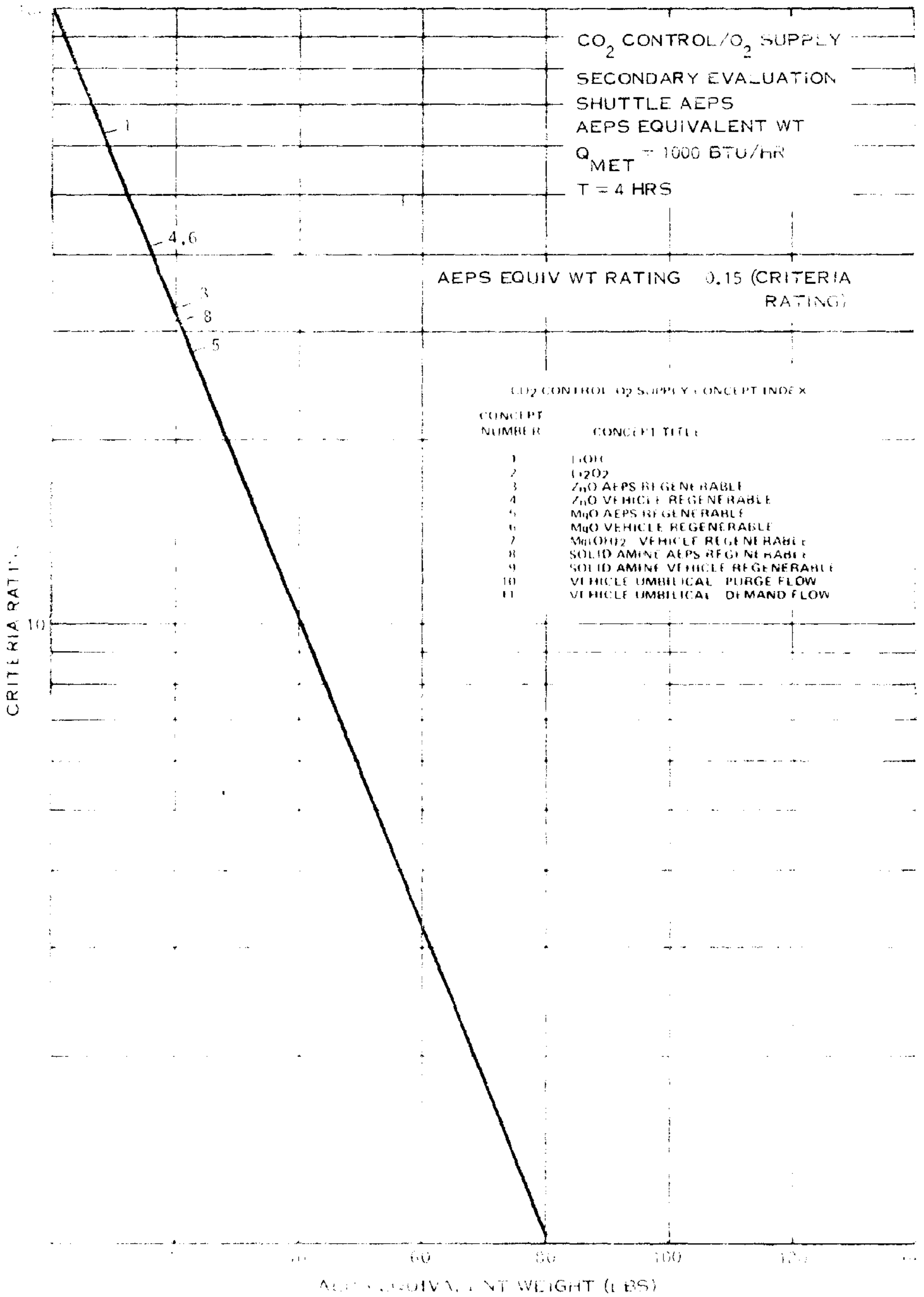
Concept	Criteria					Total
	AEPS Wt	Vehicle Vol	Interface Compatibility	Maintain	Cost	
1	15	30	25	20	10	100
2	12	30	25	20	10	97

5.2.1.2.2 CO_2 Control/O_2 Supply - Six (6) CO_2 control/O_2 supply concepts passed the primary evaluation and were carried into the secondary evaluation:

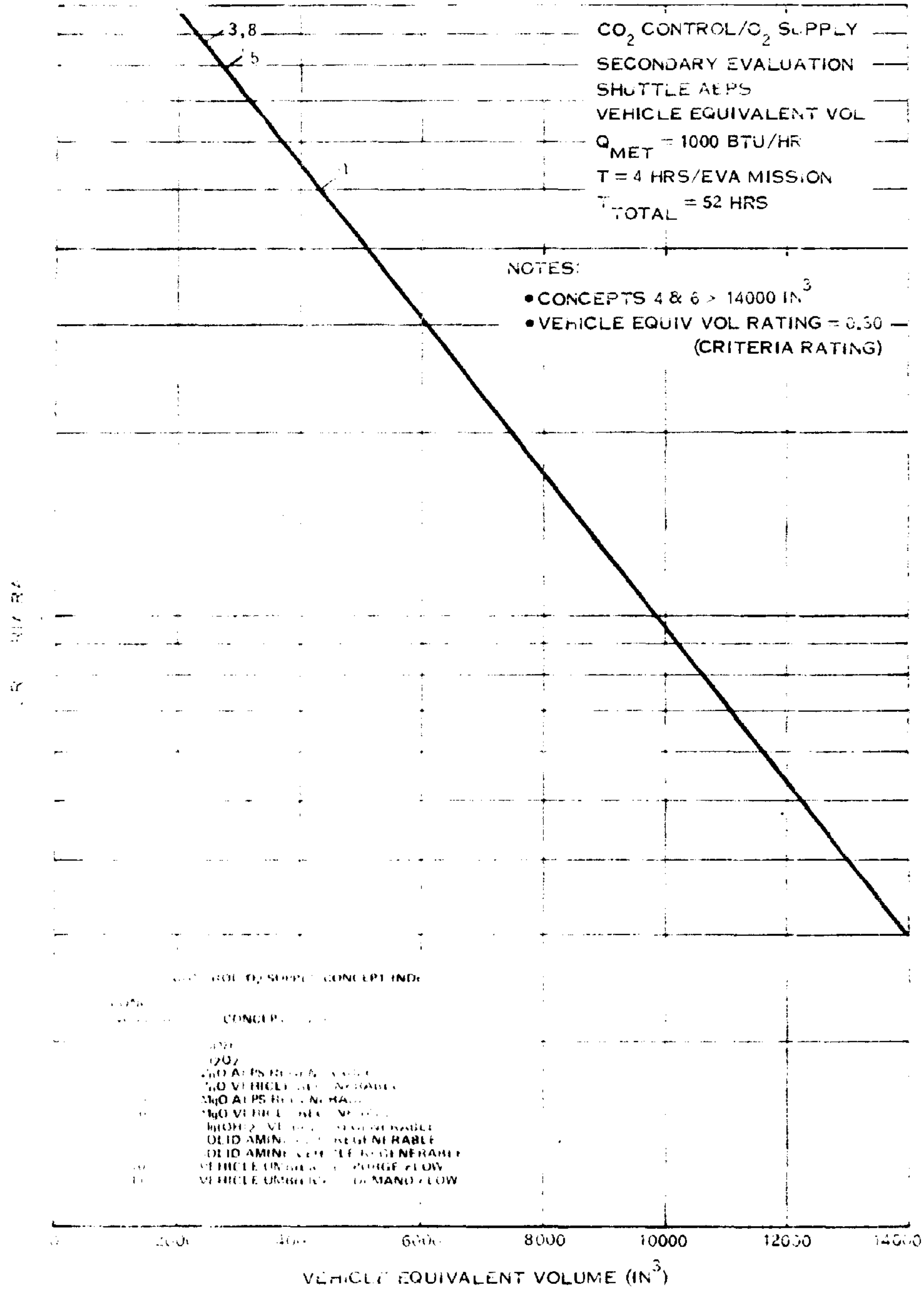
a. LiOH
b. ZnO - AEPS Regenerable
c. ZnO - Vehicle Regenerable
d. MgO - AEPS Regenerable
e. MgO - Vehicle Regenerable
f. Solid Amine - AEPS Regenerable

All of these concepts passed the secondary evaluation.

Implementation of the secondary evaluation criteria and the resultant thermal control concept ratings are presented in detail on the following pages.



CO2 CONTROL/O2 SUPPLY
SECONDARY EVALUATION
SHUTTLE AEPS
AEPS EQUIVALENT WT
QMET = 1000 BTU/HR
T = 4 HRS
1
4,6
3
8
5
AEPS EQUIV WT RATING 0.15 (CRITERIA RATING)
CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 LiOH
2 Li2O2
3 ZnO AEPS REGENERABLE
4 ZnO VEHICLE REGENERABLE
5 MgO AEPS REGENERABLE
6 MgO VEHICLE REGENERABLE
7 Mg(OH)2 VEHICLE REGENERABLE
8 SOLID AMINE AEPS REGENERABLE
9 SOLID AMINE VEHICLE REGENERABLE
10 VEHICLE UMBILICAL PURGE FLOW
11 VEHICLE UMBILICAL DEMAND FLOW
CRITERIA RATING
10
60
80
100
WEIGHT (LBS)



CO2 CONTROL/O2 SUPPLY
SECONDARY EVALUATION
SHUTTLE AEPS
VEHICLE EQUIVALENT VOL
QMET = 1000 BTU/HR
T = 4 HRS/EVA MISSION
TTOTAL = 52 HRS
NOTES:
• CONCEPTS 4 & 6 > 14000 IN3
• VEHICLE EQUIV VOL RATING = 0.30
(CRITERIA RATING)
3,8
5
1
8000
10000
VEHICLE EQUIVALENT VOLUME (IN3)

SECONDARY EVALUATION - SHUTTLE AEPS

INTERFACE COMPATIBILITY

Concept	A	B	C	Total	Rating
1	20	32	4	56	14.6
3	12	44	24	80	20.8
4	20	28	20	68	17.7
5	12	44	24	80	20.8
6	20	28	20	68	17.7
8	16	52	28	96	25.0

Notes:

A = Other AEPS Subsystem Interfaces (20 points)
B = Crew Interfaces (50 points)
C = Vehicle Interfaces (30 points)

$$\text{Interface Compatibility Rating} = \frac{\text{total}}{100} \ (25) \ (\text{Normalizing Factor})^*$$

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

SECONDARY EVALUATION - SHUTTLE AEPS

MAINTAINABILITY

Concept	A	B	C	Total	Rating
1	40	20	40	100	20
3	30	15	35	80	16
4	40	20	40	100	20
5	30	15	35	80	16
6	40	20	40	100	20
8	35	15	40	90	18

Notes:

A = Complexity of Maintenance (40 points)
B = Average Downtime (20 points)
C = Frequency of Downtimes (40 points)

Maintainability Rating $= \frac{\text{total}}{100}$ (20) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 20 points.

SECONDARY EVALUATION - SHUTTLE AEPS

COST

Concept	A	B	Total	Rating
1	0	70	70	10
3	20	30	50	7.2
4	20	40	60	8.6
5	20	30	50	7.2
6	20	40	60	8.6
8	30	40	70	10

Notes:

A = Recurring Cost
B = Nonrecurring Cost

Cost Rating $= \frac{\text{total}}{100}$ (10) (Normalizing Factor)*

*Normalizing factor upgrades all ratings to permit concept with highest rating to receive the full 10 points.

SECONDARY EVALUATION - SHUTTLE AEPS

SUMMARY

	Criteria					
Concept	AEPS Wt	Vehicle Vol	Interface Compatibility	Maintain	Cost	Total
1	15.0	17.3	14.6	20	10.0	76.9
3	7.9	30.0	20.8	16	7.2	81.9
4	10.0	0	17.7	20	8.6	56.3
5	6.7	27.3	20.8	16	7.2	78.0
6	10.0	0	17.7	20	8.6	56.3
8	7.6	30.0	25.0	18	10.0	90.6

5.2.2 Emergency Systems

5.2.2.1 Thermal Control - All candidate emergency system thermal control subsystem concepts that passed the go/no go evaluation were subjected to the comparative evaluation. Each candidate concept received a rating of from 0 to 100 for each comparative criterion. Each rating was then multiplied by the weighting factors defined in table 5-11 and the ratings added to obtain a total rating for each candidate concept.

TABLE 5-11

COMPARATIVE CRITERIA WEIGHTING FACTORS

Criteria	Weighting Factors			
	Shuttle	Space Station	Lunar Base	Mars
AEPS Equivalent Volume	0.7	0.7	0.65	0.6
AEPS Equivalent Weight	0.3	0.3	0.35	0.4

The competitive ratings for the comparative criteria were determined by establishing a straight line relationship between the criteria rating and AEPS equivalent volume or weight as the case may be, on a semi-log scale. The relationships were established by selecting criteria values that corresponded with a 100 point criteria rating and a 10 point criteria rating in accordance with table 5-12.

TABLE 5-12

Subsystem	Criterion	Mission			
		Shuttle	Space Station	Lunar Base	Mars
Thermal Control	AEPS Equivalent Volume				
	100 points	0	0	0	0
	10 points	1650 in^3	1650 in^3	3250 in^3	2500 in^3
	AEPS Equivalent Weight				
	100 points	0	0	0	0
	10 points	30 lbs	30 lbs	50 lbs	50 lbs

5.2.2 (Continued)

Table 5-13 is the index of the eight (8) candidate thermal control concepts that passed the go/no go evaluation and were carried into the comparative evaluation.

TABLE 5-13

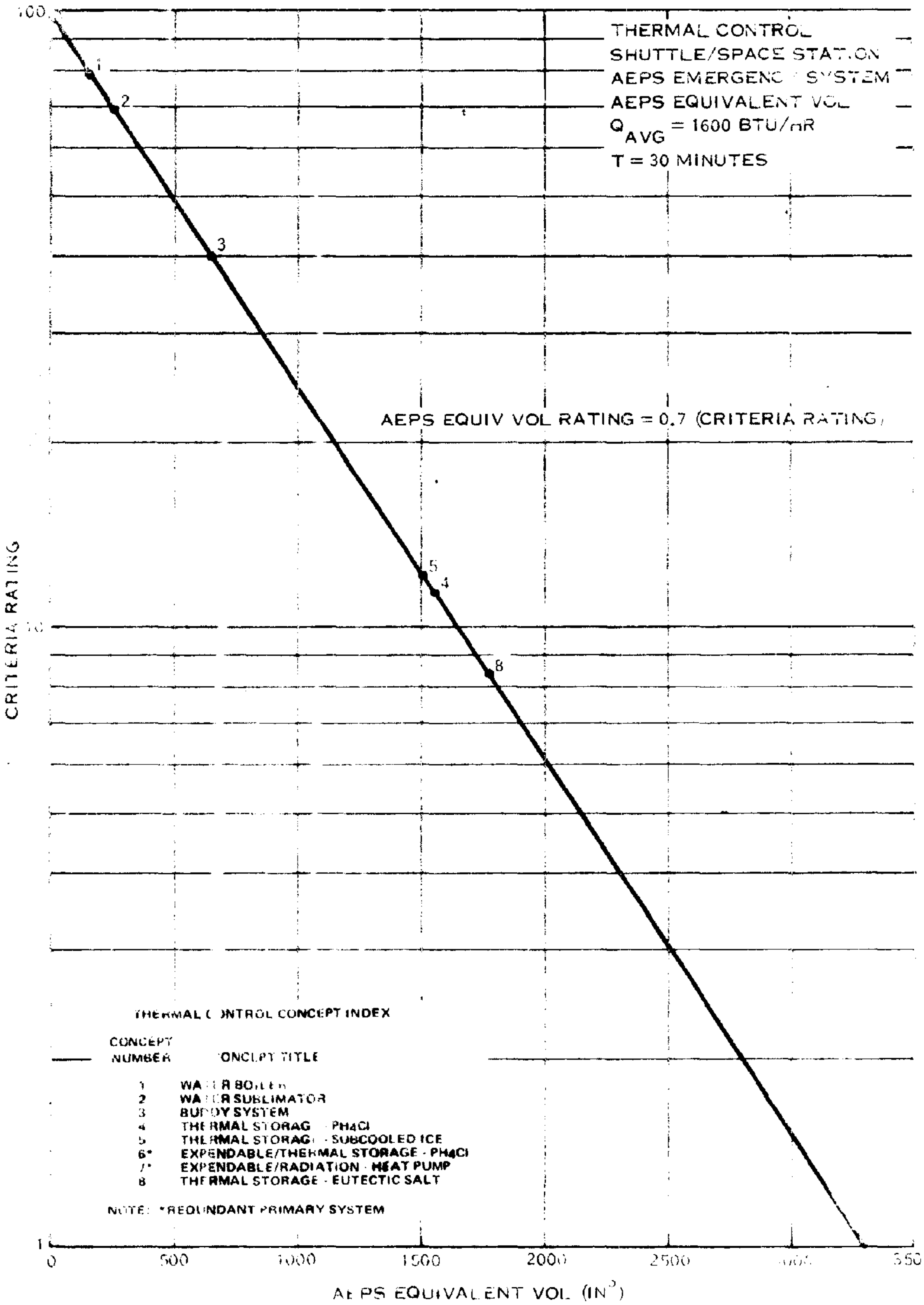
THERMAL CONTROL CONCEPT INDEX

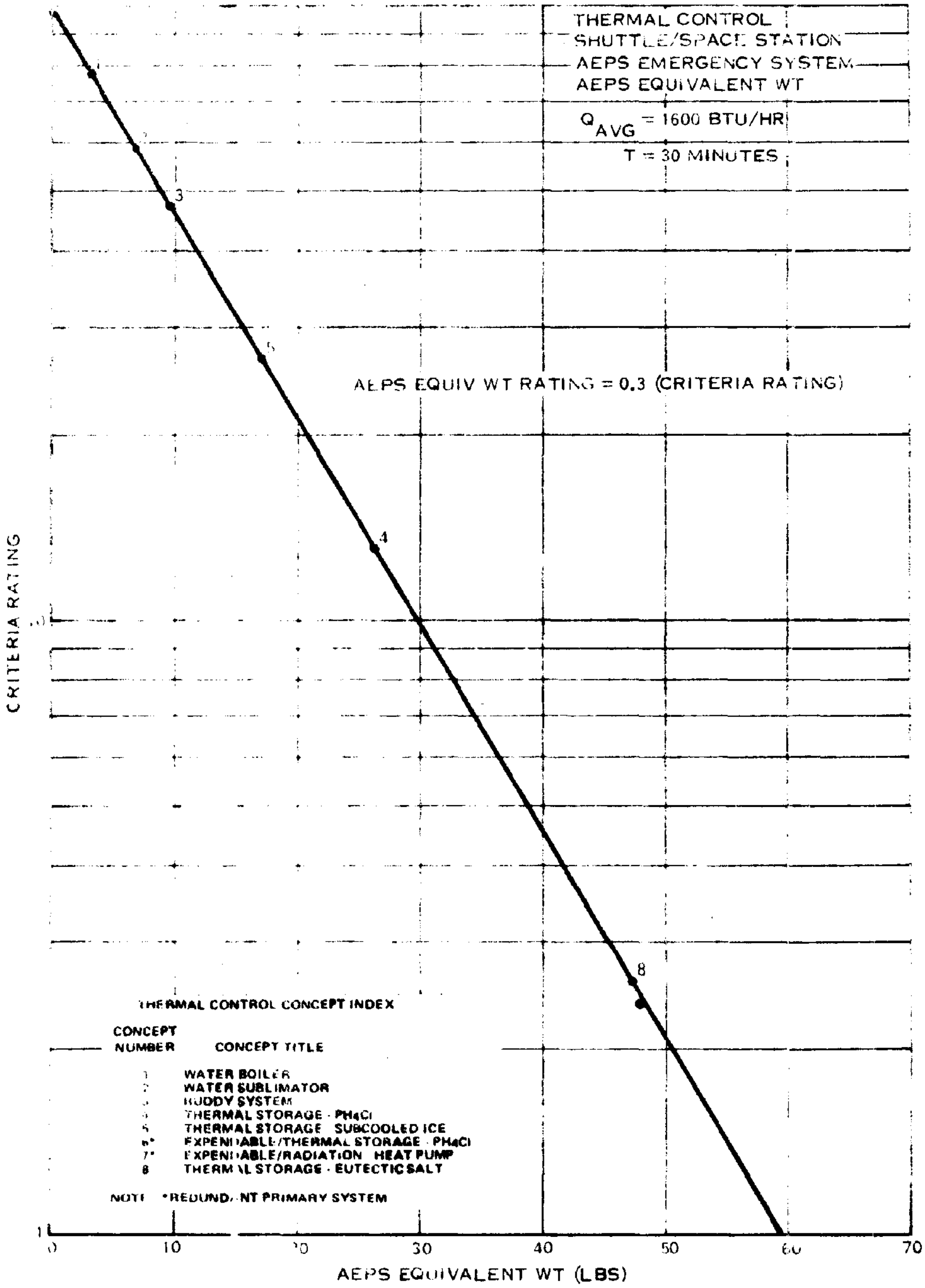
Concept Number	Concept Title
1	Water Boiler
2	Water Sublimator
3	Buddy System
4	Thermal Storage - PH_4Cl
5	Thermal Storage - Subcooled Ice
6*	Expendable/Thermal Storage - PH_4Cl
7*	Expendable/Radiation - Heat Pump
8	Thermal Storage - Eutectic Salt

NOTE: * Redundant Primary System

Implementation of the comparative evaluation criteria and the resultant candidate emergency system thermal control subsystem concept ratings are presented on the following pages.

SHUTTLE/SPACE STATION


THERMAL CONTROL
SHUTTLE/SPACE STATION
AEPS EMERGENCY SYSTEM
AEPS EQUIVALENT VOL
Q_{AVG} = 1600 BTU/HR
T = 30 MINUTES
AEPS EQUIV VOL RATING = 0.7 (CRITERIA RATING)
CRITERIA RATING
AEPS EQUIVALENT VOL (IN^3)
0
500
1000
1500
2000
2500
3500
1
10
100
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 BUDDY SYSTEM
4 THERMAL STORAGE - PH4Cl
5 THERMAL STORAGE - SUBCOOLED ICE
6* EXPENDABLE/THERMAL STORAGE - PH4Cl
7* EXPENDABLE/RADIATION - HEAT PUMP
8 THERMAL STORAGE - EUTECTIC SALT
NOTE: *REDUNDANT PRIMARY SYSTEM



THERMAL CONTROL
SHUTTLE/SPACE STATION
AEPS EMERGENCY SYSTEM
AEPS EQUIVALENT WT
Q_{AVG} = 1600 BTU/HR
T = 30 MINUTES
AEPS EQUIV WT RATING = 0.3 (CRITERIA RATING)
CRITERIA RATING
AEPS EQUIVALENT WT (LBS)
0
10
20
30
40
50
60
70
3
5
4
8
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 BUDDY SYSTEM
4 THERMAL STORAGE - PH4Cl
5 THERMAL STORAGE SUBCOOLED ICE
6* EXPENDABLE/THERMAL STORAGE - PH4Cl
7* EXPENDABLE/RADIATION HEAT PUMP
8 THERMAL STORAGE - EUTECTIC SALT
NOTE *REDUNDANT PRIMARY SYSTEM

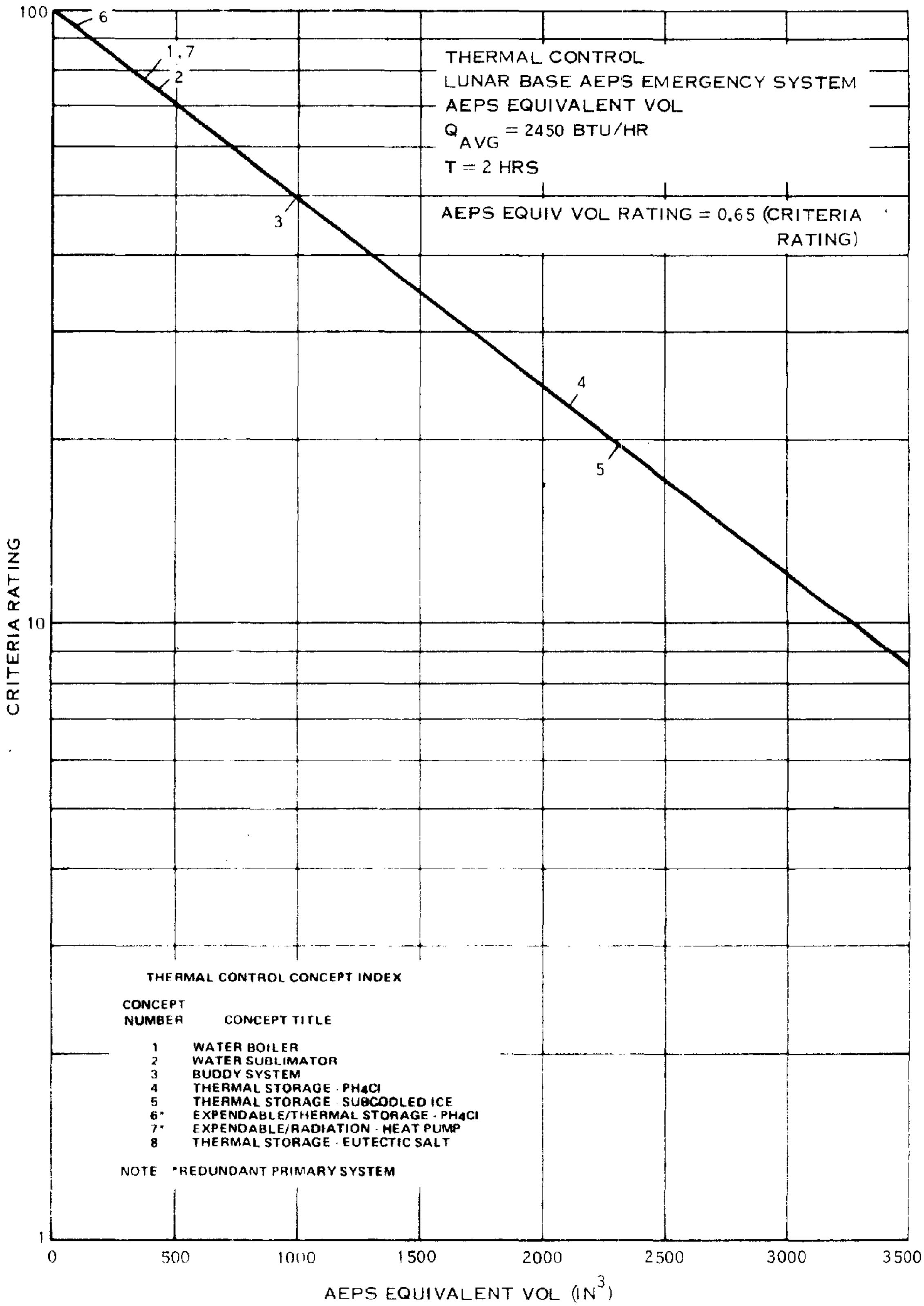
COMPARATIVE EVALUATION - SHUTTLE/SPACE STATION

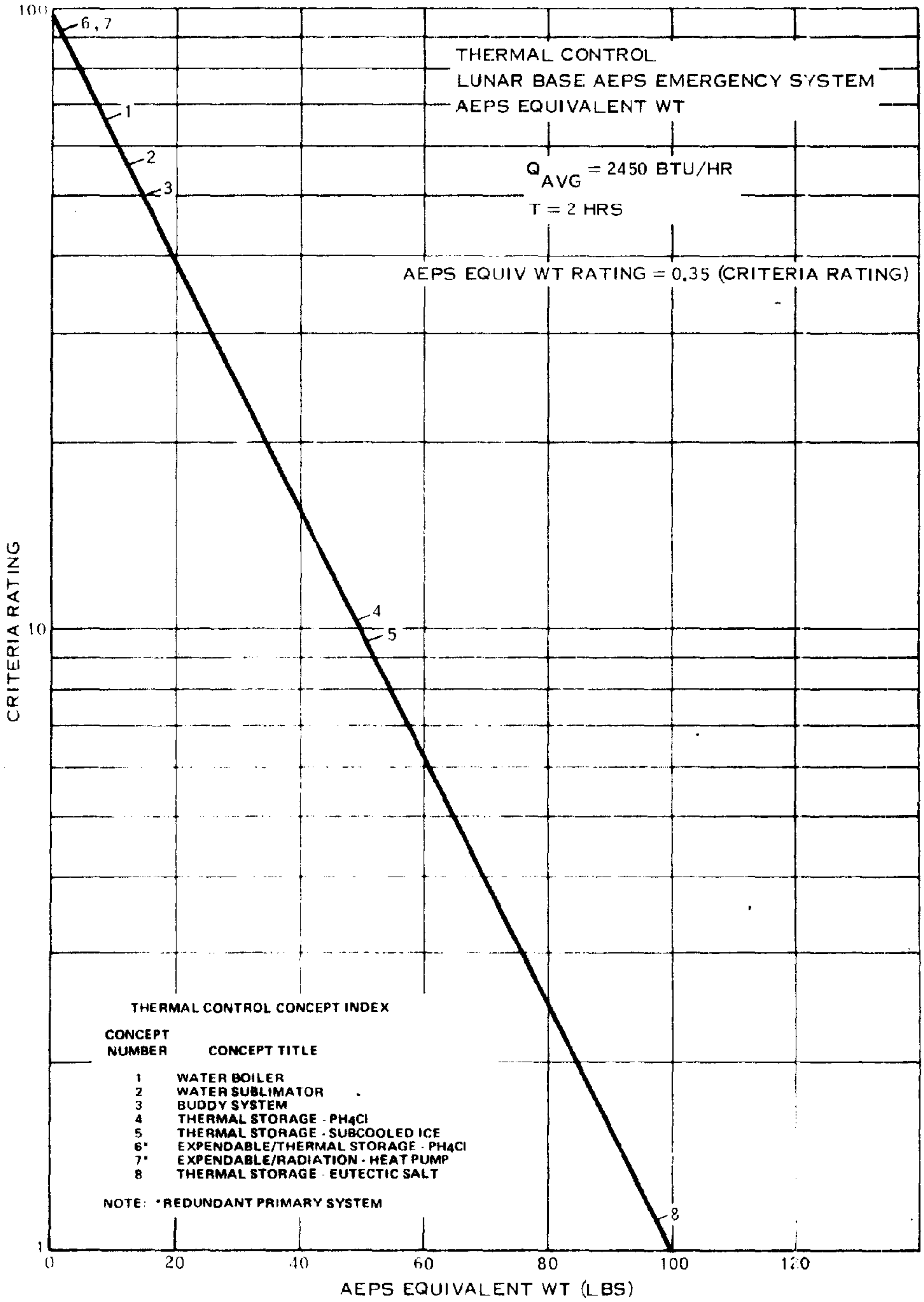
AEPS EMERGENCY SYSTEM

SUMMARY

Concept	Criteria AEPS Equivalent Volume	AEPS Equivalent Wt	Total
1	70.0	30.0	100.0
2	60.5	23.1	83.6
3	35.0	18.1	53.1
4	10.0	5.0	15.0
5	10.9	10.4	21.3
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	7.3	1.0	8.3

LUNAR BASE


THERMAL CONTROL
LUNAR BASE AEPS EMERGENCY SYSTEM
AEPS EQUIVALENT VOL
Q_{AVG} = 2450 BTU/HR
T = 2 HRS
AEPS EQUIV VOL RATING = 0.65 (CRITERIA RATING)
CRITERIA RATING
100
10
1
0
500
1000
1500
2000
2500
3000
3500
AEPS EQUIVALENT VOL (IN^3)
6
1, 7
2
3
4
5
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 BUDDY SYSTEM
4 THERMAL STORAGE - PH4Cl
5 THERMAL STORAGE - SUBCOOLED ICE
6* EXPENDABLE/THERMAL STORAGE - PH4Cl
7* EXPENDABLE/RADIATION - HEAT PUMP
8 THERMAL STORAGE - EUTECTIC SALT
NOTE *REDUNDANT PRIMARY SYSTEM



THERMAL CONTROL
LUNAR BASE AEPS EMERGENCY SYSTEM
AEPS EQUIVALENT WT
Q_{AVG} = 2450 BTU/HR
T = 2 HRS
AEPS EQUIV WT RATING = 0.35 (CRITERIA RATING)
CRITERIA RATING
100
10
1
AEPS EQUIVALENT WT (LBS)
0
20
40
60
80
100
120
6, 7
1
2
3
4
5
8
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 BUDDY SYSTEM
4 THERMAL STORAGE - PH4Cl
5 THERMAL STORAGE - SUBCOOLED ICE
6* EXPENDABLE/THERMAL STORAGE - PH4Cl
7* EXPENDABLE/RADIATION - HEAT PUMP
8 THERMAL STORAGE - EUTECTIC SALT
NOTE: *REDUNDANT PRIMARY SYSTEM

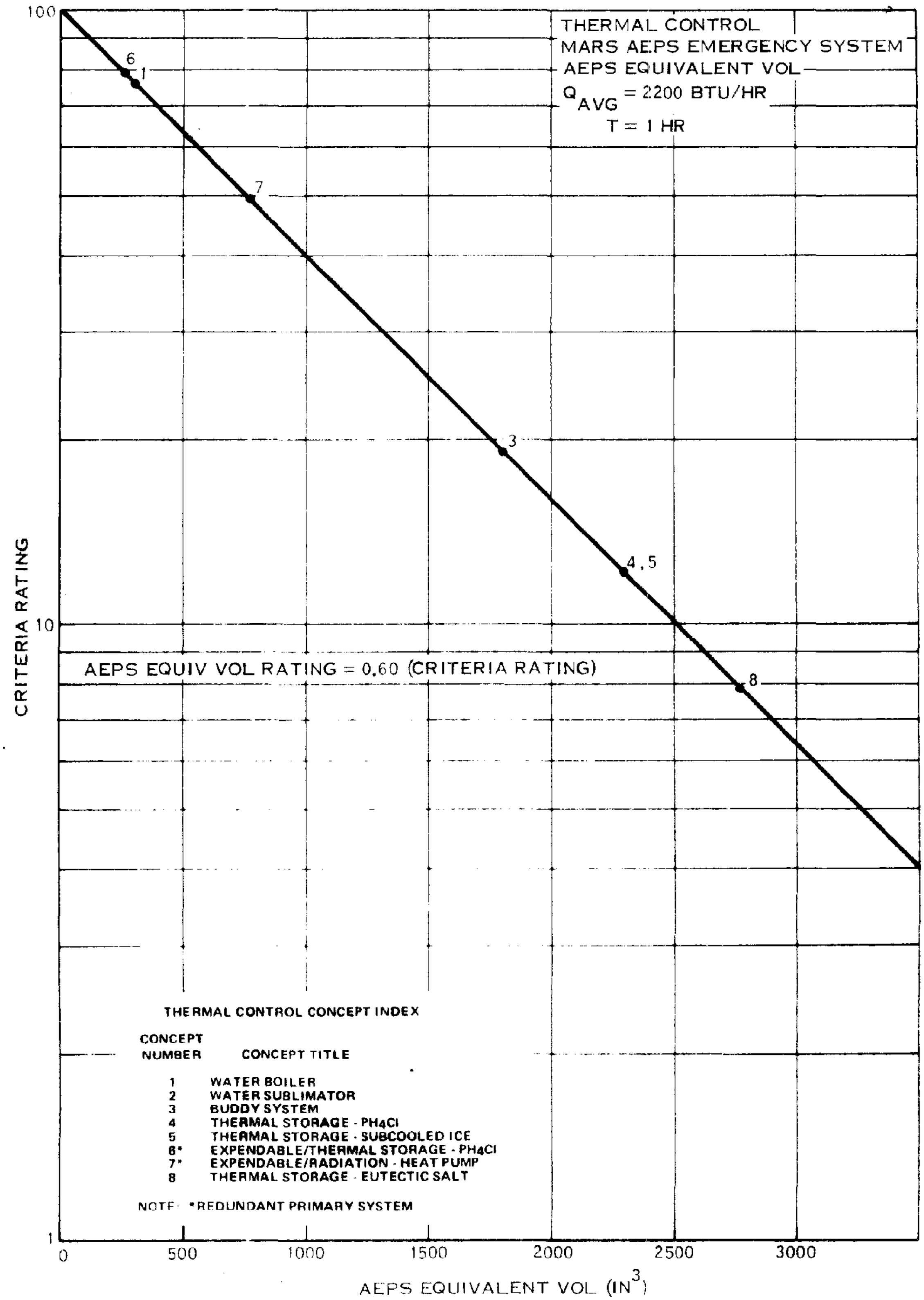
COMPARATIVE EVALUATION - LUNAR BASE

AEPS EMERGENCY SYSTEM

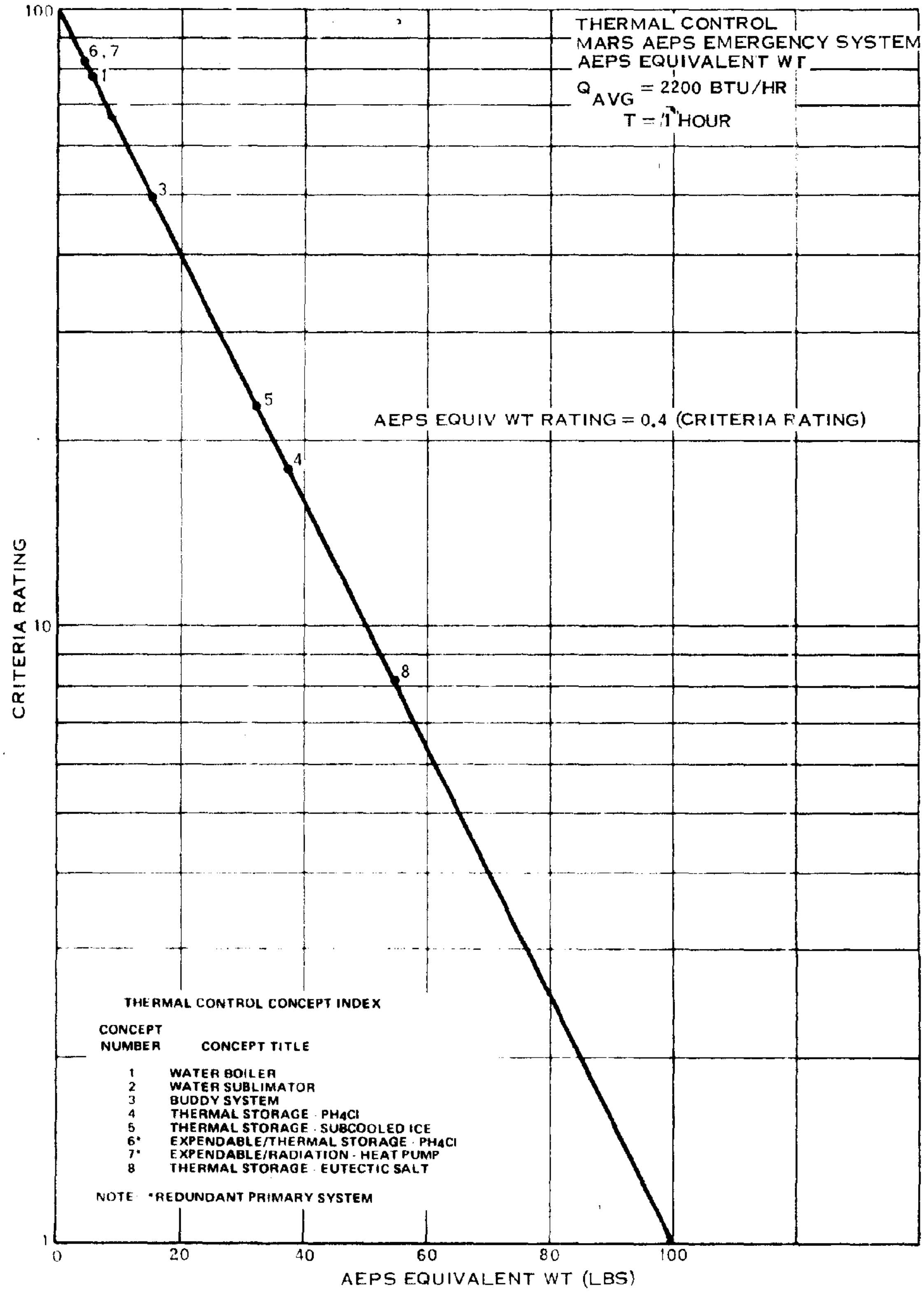
SUMMARY

Concept	AEPS Equivalent Volume	AEPS Equivalent Wt	Total
1	53.5	27.7	79.2
2	51.5	21.8	73.3
3	34.2	19.5	53.7
4	15.7	3.9	19.6
5	13.7	3.7	17.4
6	65.0	35.0	100.0
7	53.5	35.0	88.5
8	0	0.4	0.4

MARS



THERMAL CONTROL
MARS AEPS EMERGENCY SYSTEM
AEPS EQUIVALENT VOL
Q_{AVG} = 2200 BTU/HR
T = 1 HR
AEPS EQUIV VOL RATING = 0.60 (CRITERIA RATING)
CRITERIA RATING
AEPS EQUIVALENT VOL. (IN^3)
100
10
1
0
500
1000
1500
2000
2500
3000
6
1
7
3
4, 5
8
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 BUDDY SYSTEM
4 THERMAL STORAGE - PH4Cl
5 THERMAL STORAGE - SUBCOOLED ICE
6* EXPENDABLE/THERMAL STORAGE - PH4Cl
7* EXPENDABLE/RADIATION - HEAT PUMP
8 THERMAL STORAGE - EUTECTIC SALT
NOTE: *REDUNDANT PRIMARY SYSTEM


THERMAL CONTROL
MARS AEPS EMERGENCY SYSTEM
AEPS EQUIVALENT WT
Q_{AVG} = 2200 BTU/HR
T = 1 HOUR
AEPS EQUIV WT RATING = 0.4 (CRITERIA RATING)
CRITERIA RATING
AEPS EQUIVALENT WT (LBS)
100
10
1
0
20
40
60
80
100
6, 7
1
3
5
4
8
THERMAL CONTROL CONCEPT INDEX
CONCEPT NUMBER
CONCEPT TITLE
1 WATER BOILER
2 WATER SUBLIMATOR
3 BUDDY SYSTEM
4 THERMAL STORAGE - PH4Cl
5 THERMAL STORAGE - SUBCOOLED ICE
6* EXPENDABLE/THERMAL STORAGE - PH4Cl
7* EXPENDABLE/RADIATION - HEAT PUMP
8 THERMAL STORAGE - EUTECTIC SALT
NOTE: *REDUNDANT PRIMARY SYSTEM

COMPARATIVE EVALUATION - MARS AEPS

EMERGENCY SYSTEM

SUMMARY

Concept	Criteria AEPS Equivalent Volume	AEPS Equivalent Wt	Total
1	53.5	39.0	92.5
3	33.4	24.4	57.8
4	13.0	8.8	21.8
5	13.0	11.2	24.2
6	60.0	40.0	100.0
7	42.0	40.0	82.0
8	8.3	4.0	12.3

5.2.2.2 CO_2 Control/O_2 Supply - Due to the overall system implications of some of the candidate CO_2 control/O_2 supply concepts (specifically the open loop and semi-open loop concepts), this evaluation was conducted on the system level.

6.0 RESULTS AND RECOMMENDATIONS

6.0. RESULTS AND RECOMMENDATIONS

This section contains a summary of the thermal control and CO_2 control/O_2 supply subsystem evaluation results, recommendations for the thermal control and CO_2 control/O_2 supply concepts to be carried into the system studies, and the updated parametric analyses of the recommended subsystem concepts.

6.1. Phase One Effort

6.1.1. Evaluations Results

6.1.1.1. Thermal Control - The thermal control subsystem evaluations resulted in the selection of thermal control concepts from the following basic categories:

a. Expendable
b. Radiation
c. Thermal storage
d. Combinations of the above.

Specifically, of the original 55 thermal control concepts identified at the onset of the AEPS study, the following 6 concepts successfully passed the go/no go, primary and secondary evaluations:

a. Water Boiler
b. Water Sublimator
c. Thermal Storage - PH_4Cl
d. Expendable/Direct Radiative Cooling
e. Expendable/Radiation
f. Expendable/Thermal Storage - PH_4Cl

However the Thermal Storage - PH_4Cl and Expendable/Thermal Storage - PH_4Cl concepts passed the go/no go evaluation with a marginal acceptance in the areas of safety and crew acceptability. Both concepts were reevaluated in these areas during the system studies.

6.1.1.2. CO_2 Control - The CO_2 Control/O_2 supply subsystem evaluations resulted in the selection of CO_2 control concepts from one basic category - solid regenerable CO_2 sorbents - all combined with a high pressure gaseous oxygen supply. Specifically, of the original 45 combined CO_2 control/O_2 supply concepts identified at the onset of the AEPS study, the following 5 concepts successfully passed the go/no go, primary and secondary evaluations:

a. Magnesium Oxide-Vehicle Regenerable/High Pressure Gaseous O_2 Supply

6.1.1.2. (continued)

- b. Zinc Oxide - Vehicle Regenerable/High Pressure Gaseous O_2 Supply
- c. Magnesium Oxide - AEPS Regenerable/High Pressure Gaseous O_2 Supply
- d. Zinc Oxide - AEPS Regenerable/High Pressure Gaseous O_2 Supply
- e. Solid Amine - AEPS Regenerable/High Pressure Gaseous O_2 Supply.

6.1.2. Recommendations

6.1.2.1. Thermal Control - The following 5 thermal control subsystem concepts were recommended to be carried into the system studies:

- a. Water Boiler
- b. Thermal Storage - PH_4Cl
- c. Expendable/Direct Radiative Cooling
- d. Expendable/Radiation
- e. Expendable/Thermal Storage - PH_4Cl.

To simplify the AEPS system studies effort, and because the presence of an atmosphere on Mars does not permit operation of a water sublimator there, the water boiler was the only expendable water concept recommended to be carried into the system studies. Both the water boiler and water sublimator were rated nearly equal throughout the subsystem evaluations and although both concepts have been flight-qualified and flown on a number of space missions, both would require additional design and development to meet the longer life requirements of the space programs being discussed for the 1980's. This deletion of the water sublimator concept is not to be misconstrued as the total elimination of this concept from further consideration during the remainder of the study or from any research and development program which might result from the new technology recommendations generated at the conclusion of this study.

6.1.2.2. CO_2 Control/O_2 Supply - The following CO_2 control/O_2 supply concepts were recommended to be carried into the system studies:

- a. Zinc Oxide - Vehicle Regenerable/High Pressure Gaseous O_2 Supply
- b. Zinc Oxide - AEPS Regenerable/High Pressure Gaseous O_2 Supply
- c. Solid Amine - AEPS Regenerable/High Pressure Gaseous O_2 Supply

Zinc oxide has a greater theoretical CO_2 removal capacity per unit volume of sorbent and is regenerable at a lower temperature than magnesium oxide. Therefore, to simplify the AEPS system system study effort, the metallic oxide CO_2 control concepts utilizing

6.1.2.2. (continued)

zinc oxide were the only metallic oxide CO_2 control concepts recommended to be carried into the system studies. Magnesium oxide will be retained as a backup for the zinc oxide.

6.1.3. Recommended Subsystems Parametric Analyses

After completion of the primary and secondary evaluations, the AEPS specification requirements for each of the three missions - Space Station, Lunar Base and Mars - were reviewed and updated to reflect the latest mission projections. Based upon these updated specification requirements, the original parametric analyses of the recommended subsystem concepts were reviewed and updated, as required. The following parametric data is presented for each of the three missions for all the recommended thermal control and CO_2 control/O_2 supply subsystems:

a. Vehicle equivalent weight versus total mission duration
b. Vehicle equivalent volume versus total mission duration
c. AEPS equivalent volume versus EVA mission duration
d. AEPS equivalent weight versus EVA mission duration
e. Accumulated resupply launch weight versus number of resupplies (Space Station and Lunar Base only).

The updated parametric analyses are presented in the following figures:

- Thermal control for Space Station AEPS - Figure 6-1 through 6-5
- Thermal control for Lunar Base AEPS - Figures 6-6 through 6-10
- Thermal control for Mars AEPS - Figures 6-11 through 6-14
- CO_2 Control/O_2 Supply for Space Station AEPS - Figures 6-15 through 6-19
- CO_2 Control/O_2 Supply for Lunar Base AEPS - Figures 6-20 through 6-24
- CO_2 Control/O_2 Supply for Mars AEPS - Figures 6-25 through 6-28

Note that the accumulated resupply launch weight versus number of resupplies parametric data indicates that CO_2 reduction only trades off when there are three (3) or more resupplies.

THERMAL CONTROL

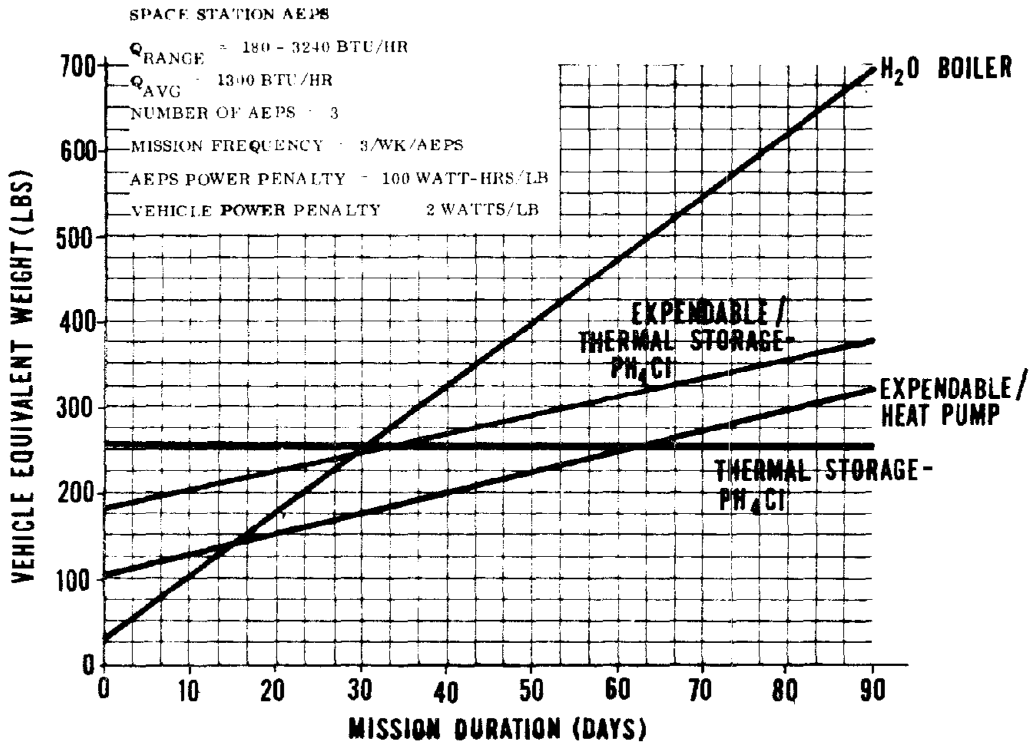


FIGURE 6—1

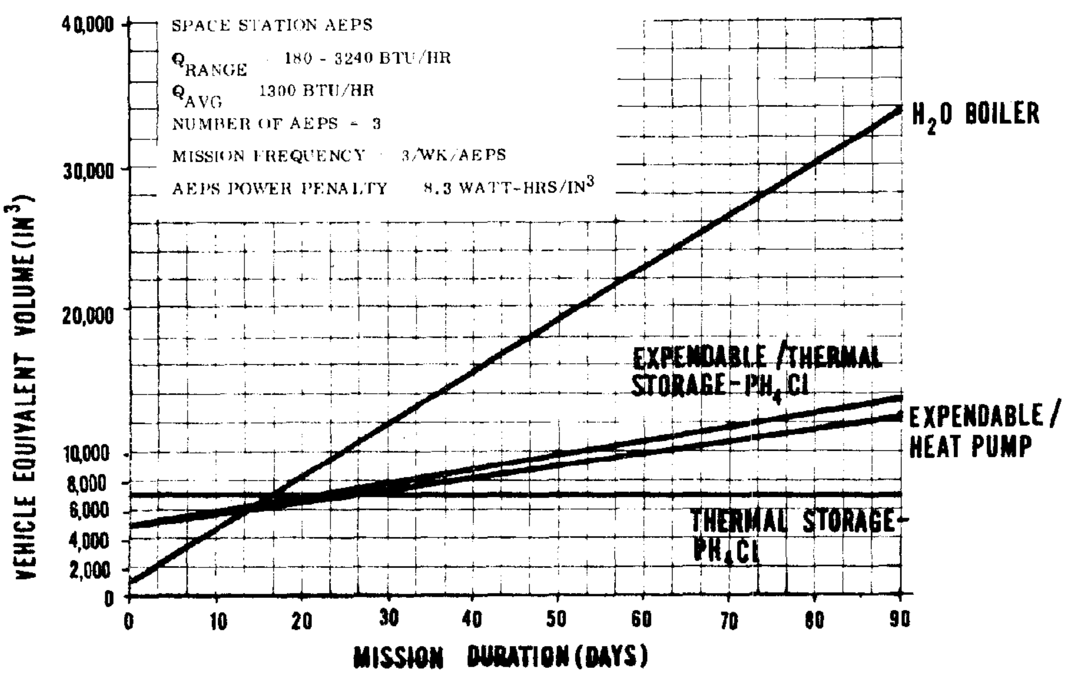


FIGURE 6—2

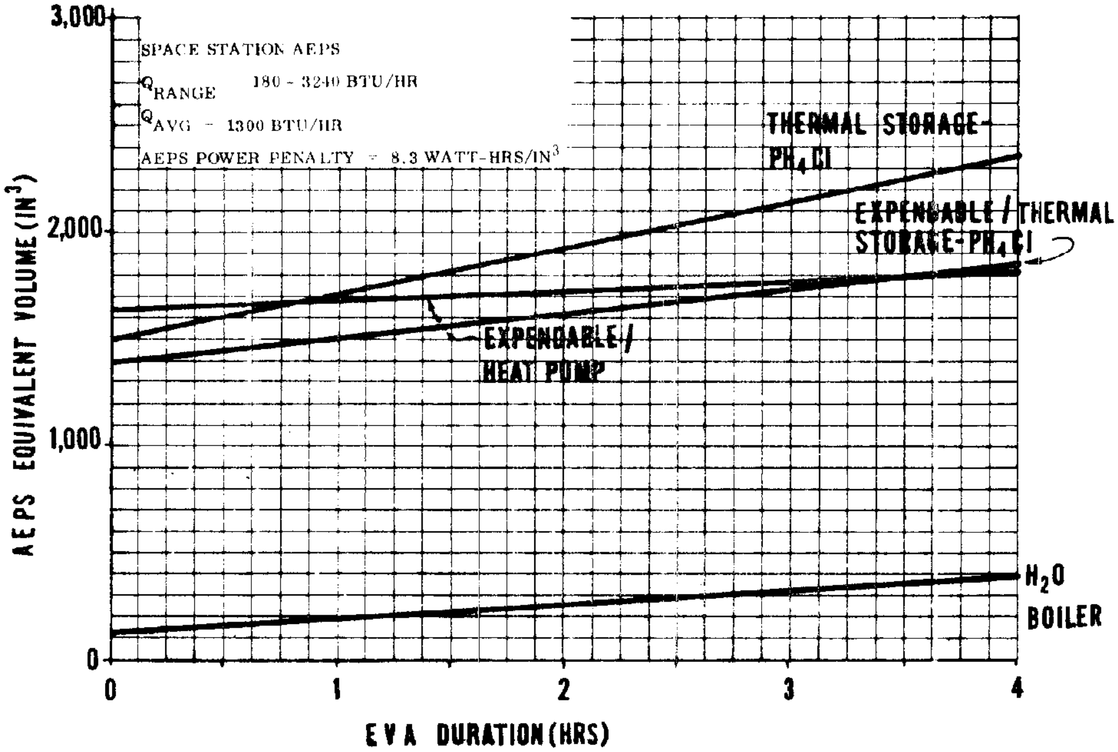


FIGURE 6–3

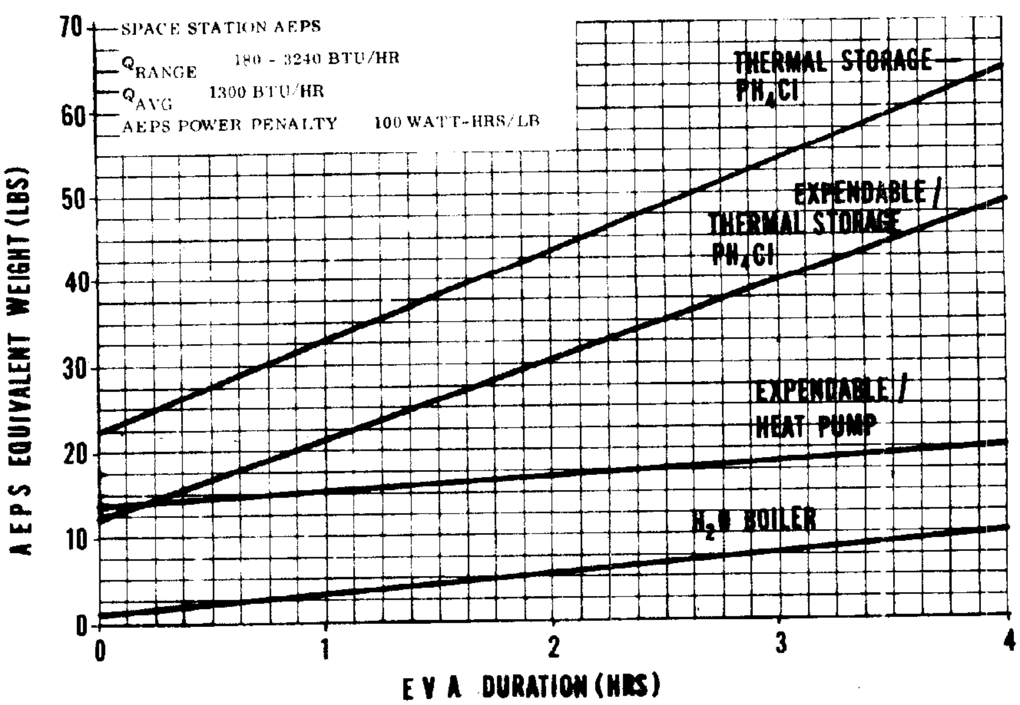
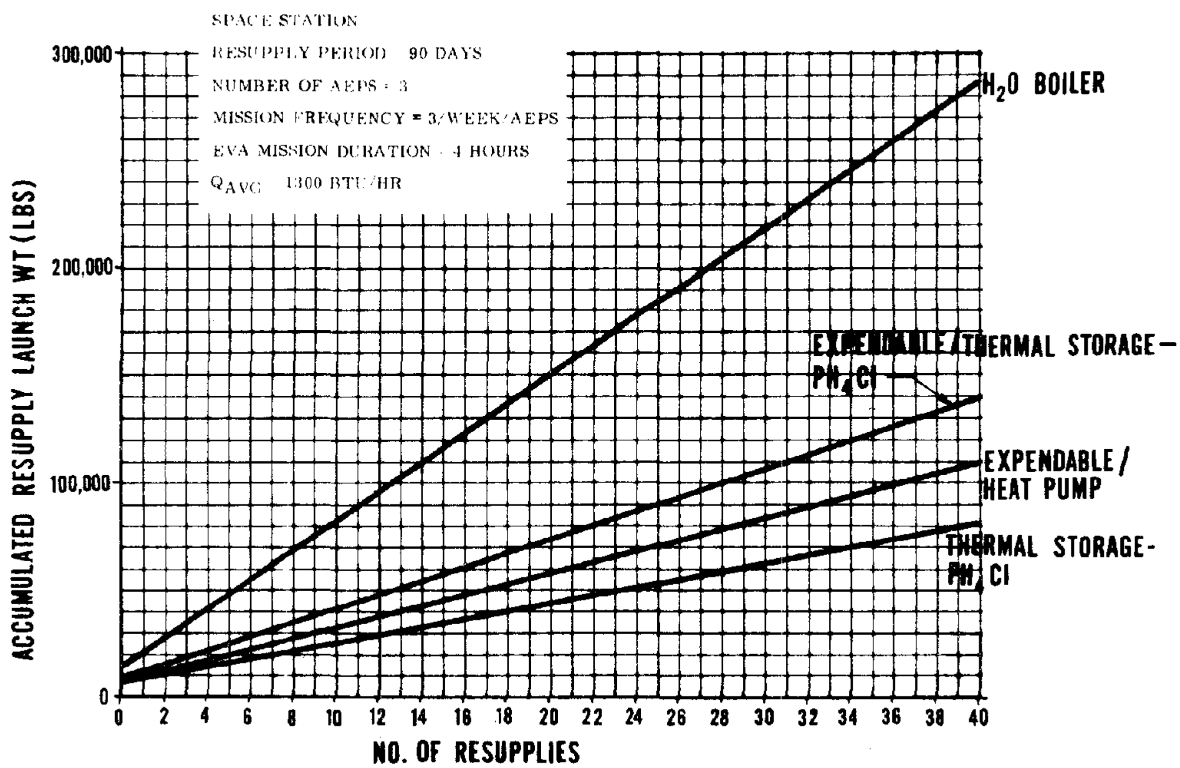


FIGURE 6–4



SPACE STATION
RESUPPLY PERIOD 90 DAYS
NUMBER OF AEPS = 3
MISSION FREQUENCY = 3/WEEK/AEPS
EVA MISSION DURATION = 4 HOURS
Q_{AVG} 1300 BTU/HR
300,000
200,000
100,000
0
ACCUMULATED RESUPPLY LAUNCH WT (LBS)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
NO. OF RESUPPLIES
H_2O BOILER
EXPENDABLE/THERMAL STORAGE–PH_4Cl
EXPENDABLE/HEAT PUMP
THERMAL STORAGE-PH_4Cl

FIGURE 6–5

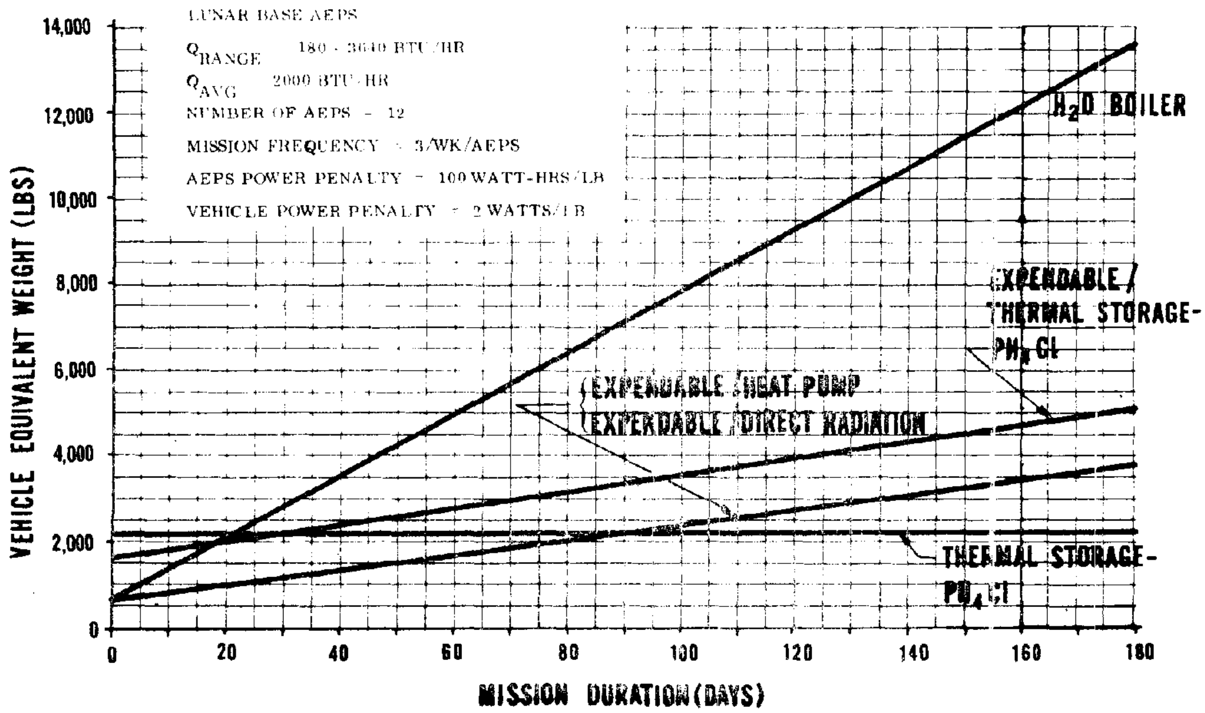


FIGURE 6-6

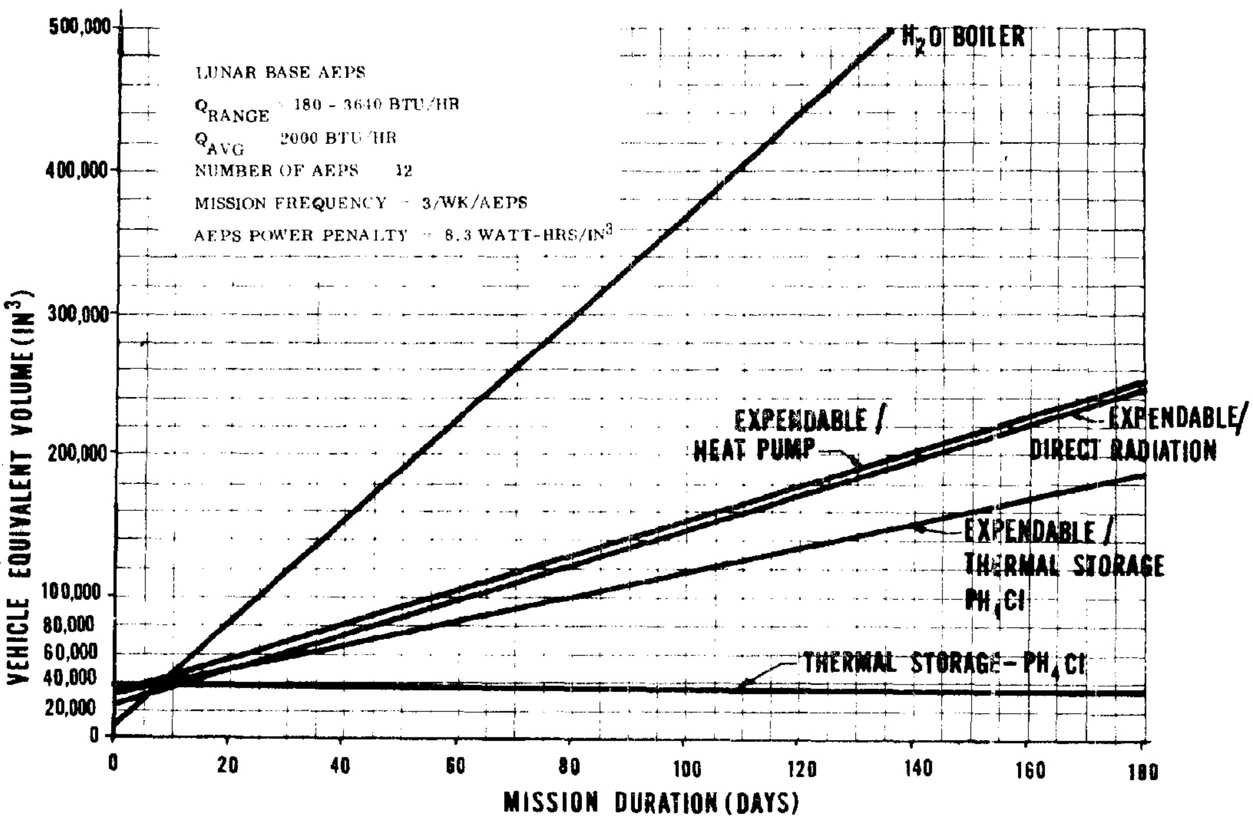


FIGURE 6-7

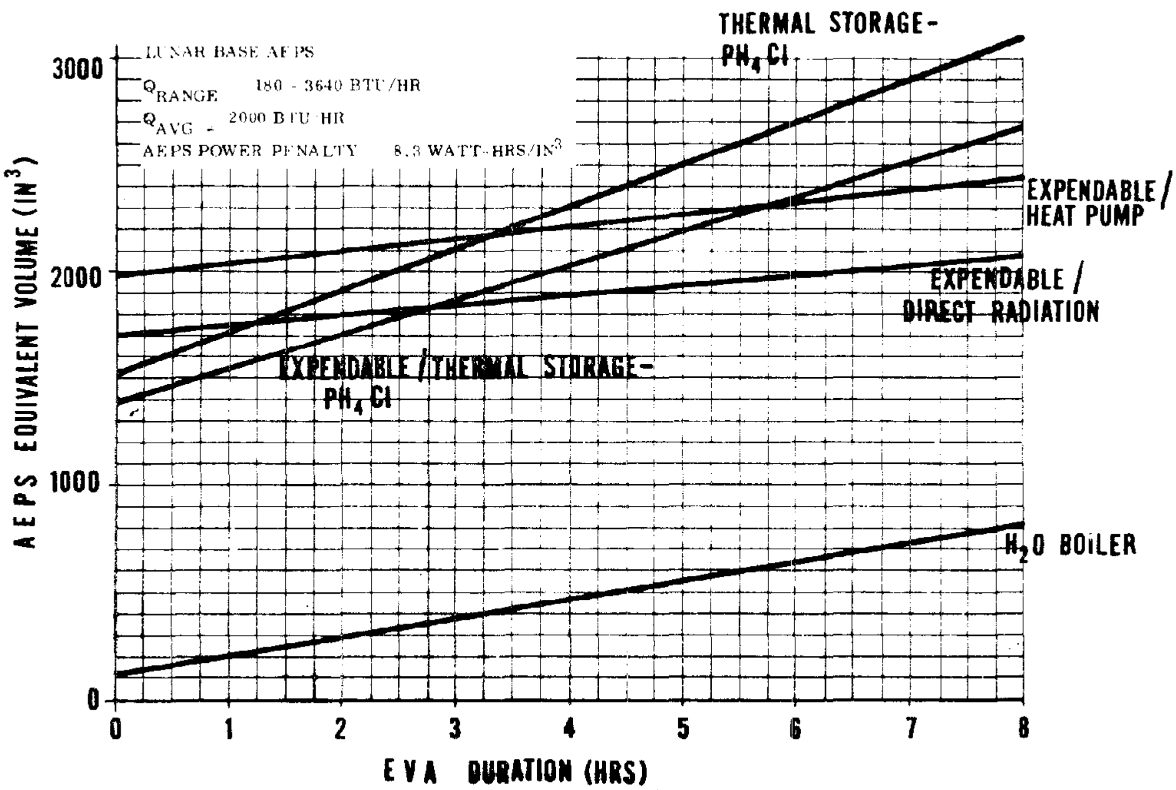


FIGURE 6–8

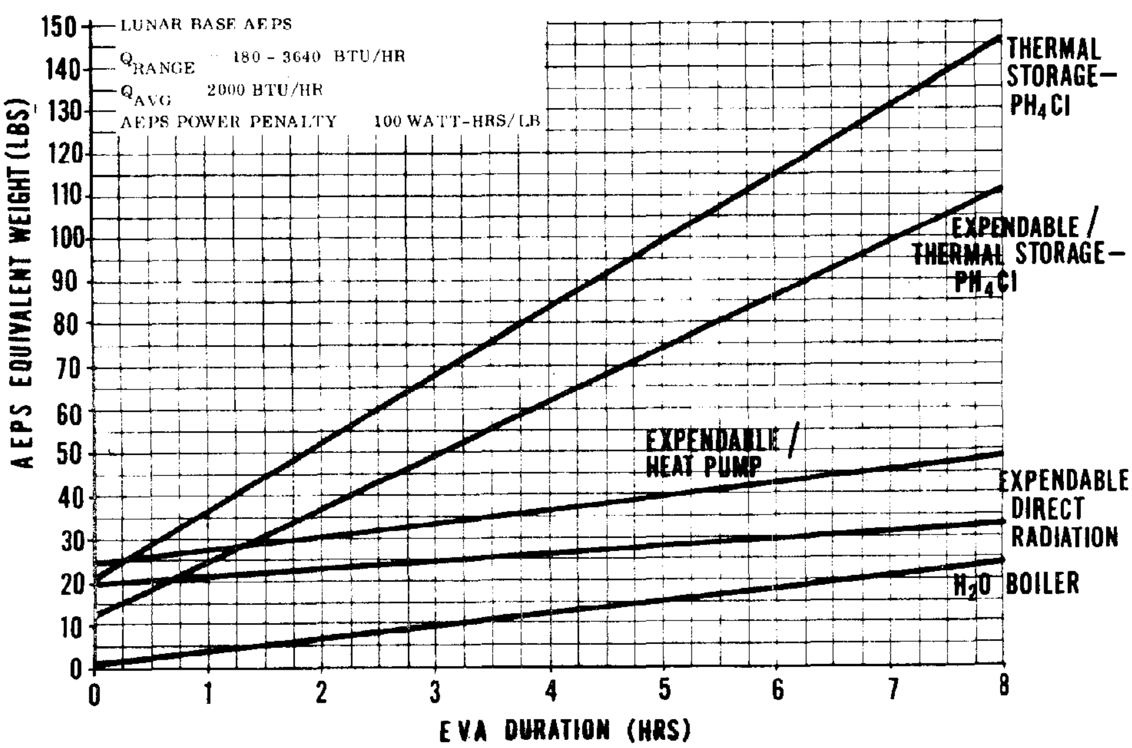


FIGURE 6–9

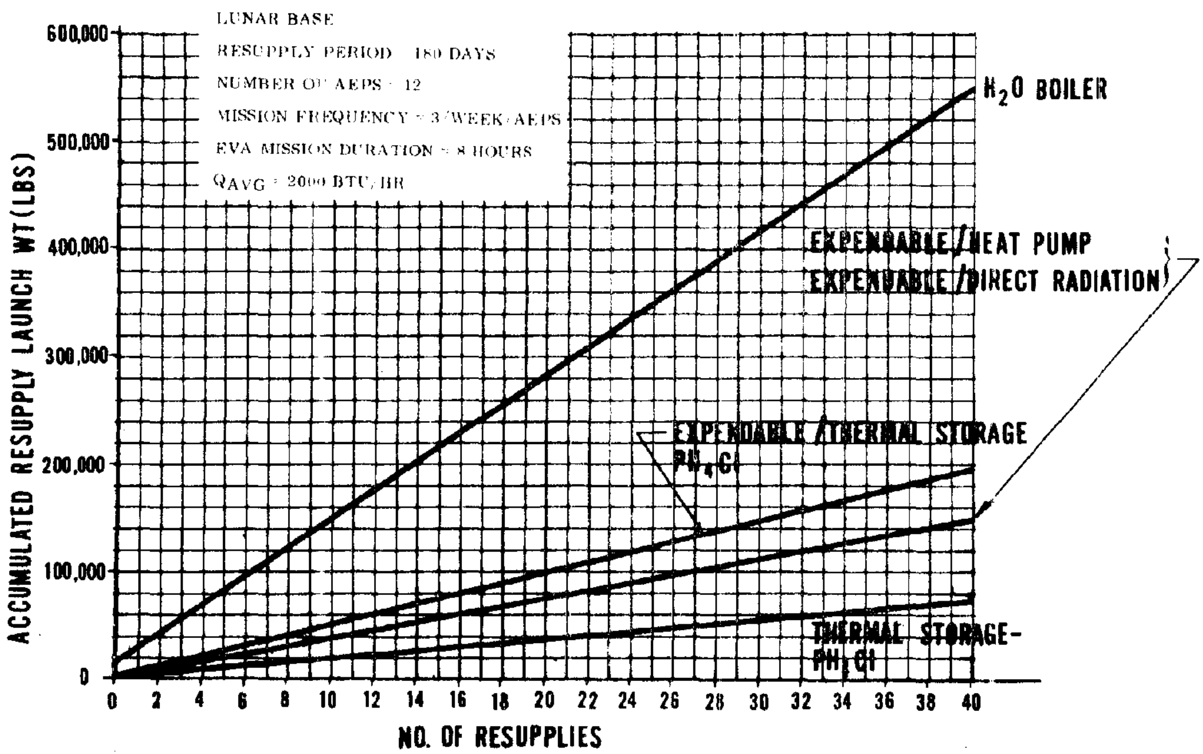

LUNAR BASE
RESUPPLY PERIOD = 180 DAYS
NUMBER OF AEPS = 12
MISSION FREQUENCY = 3/WEEK/AEPS
EVA MISSION DURATION = 8 HOURS
Q_{AVG} = 2000 BTU/HR
ACCUMULATED RESUPPLY LAUNCH WT(LBS)
600,000
500,000
400,000
300,000
200,000
100,000
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
NO. OF RESUPPLIES
H_2O BOILER
EXPENDABLE/HEAT PUMP
EXPENDABLE/DIRECT RADIATION
EXPENDABLE/THERMAL STORAGE PH_4Cl
THERMAL STORAGE-PH_4Cl

FIGURE 6–10

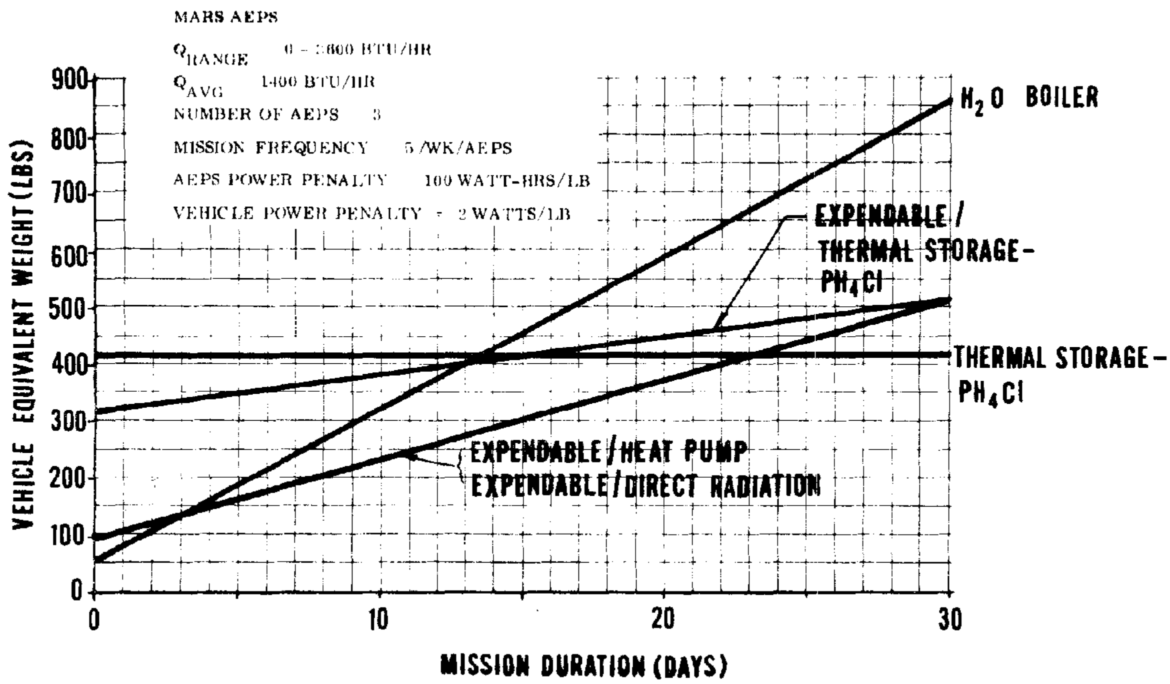


FIGURE 6–11

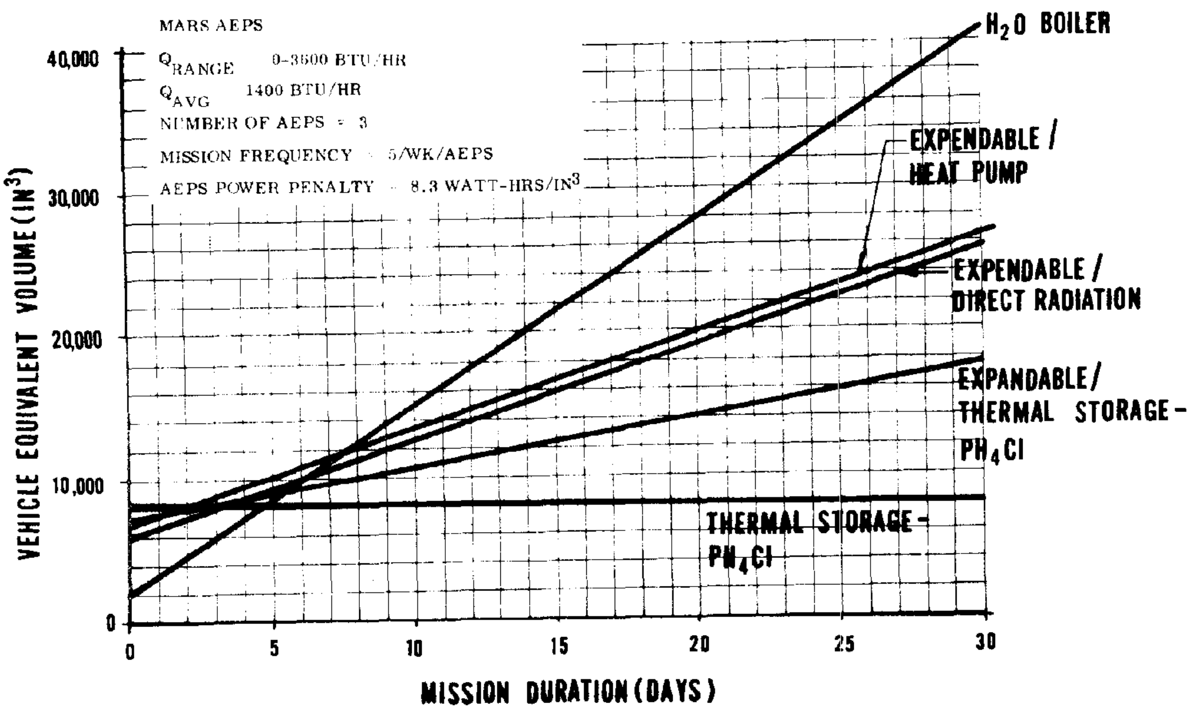


FIGURE 6—12

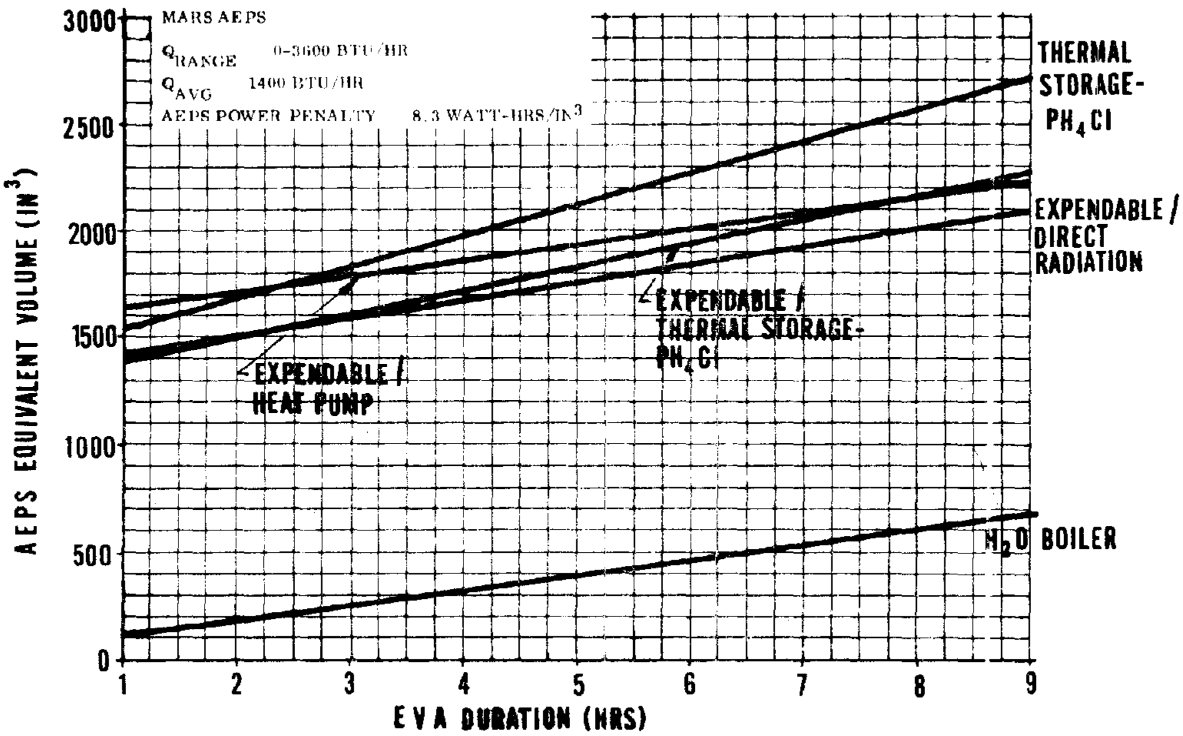


FIGURE 6–13

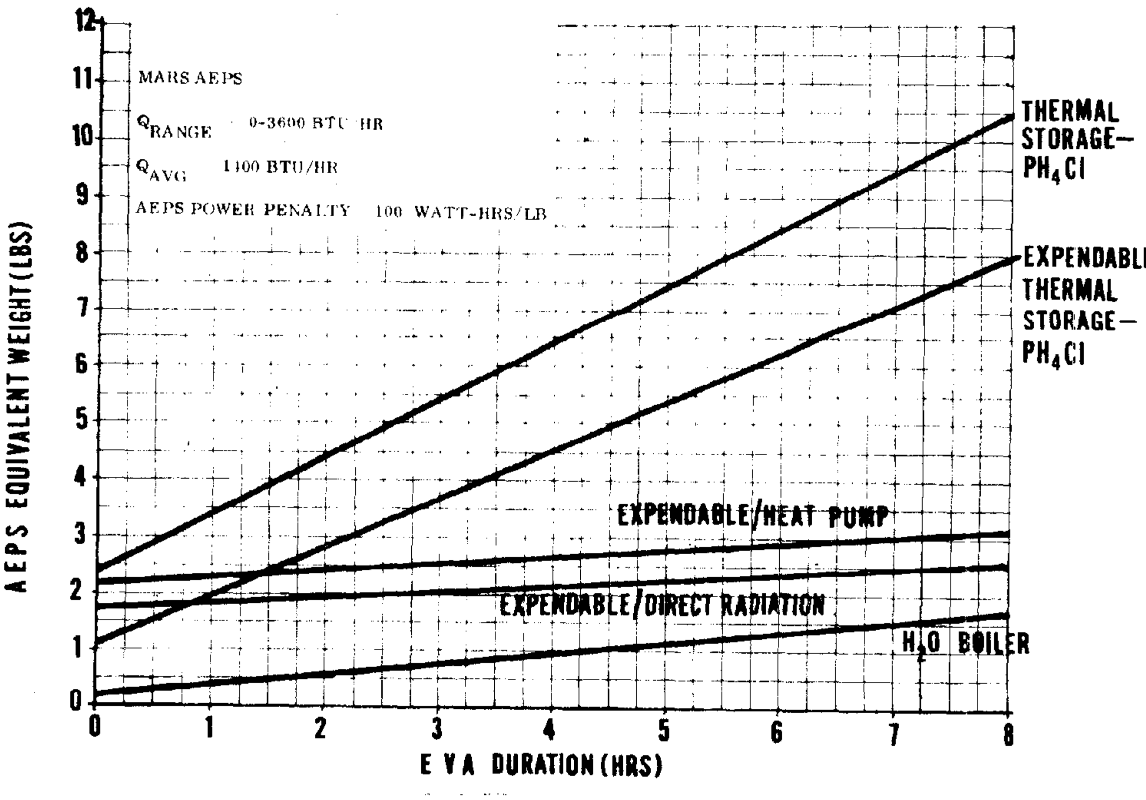


FIGURE 6–14

CO_2 CONTROL/O_2 SUPPLY

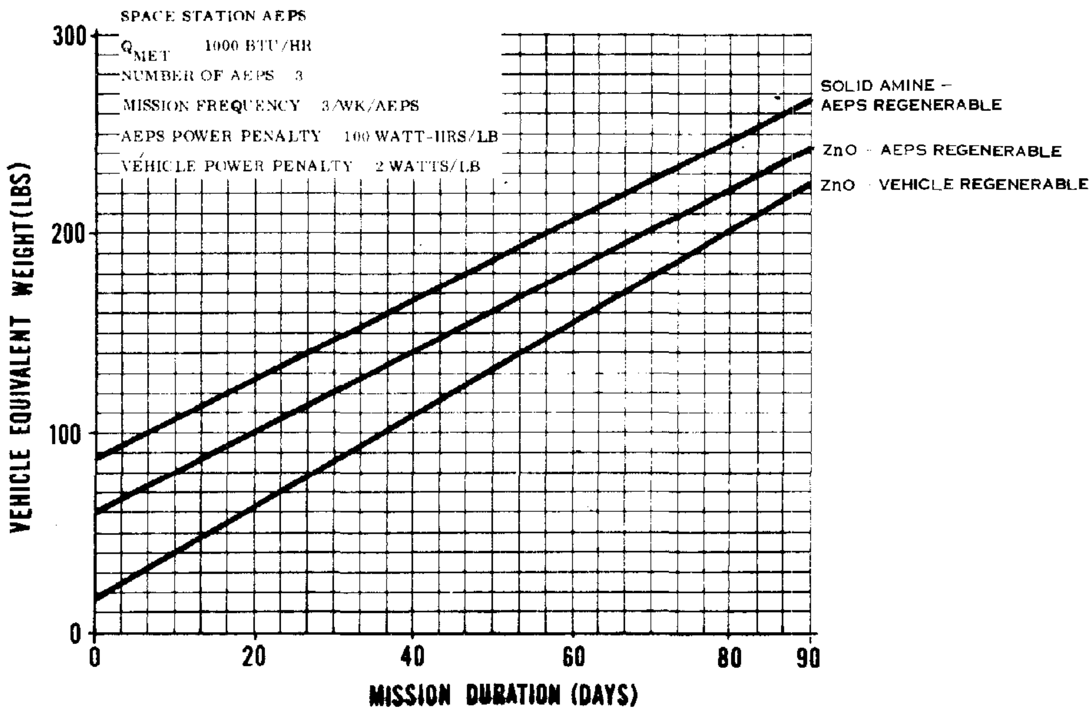


FIGURE 6–15

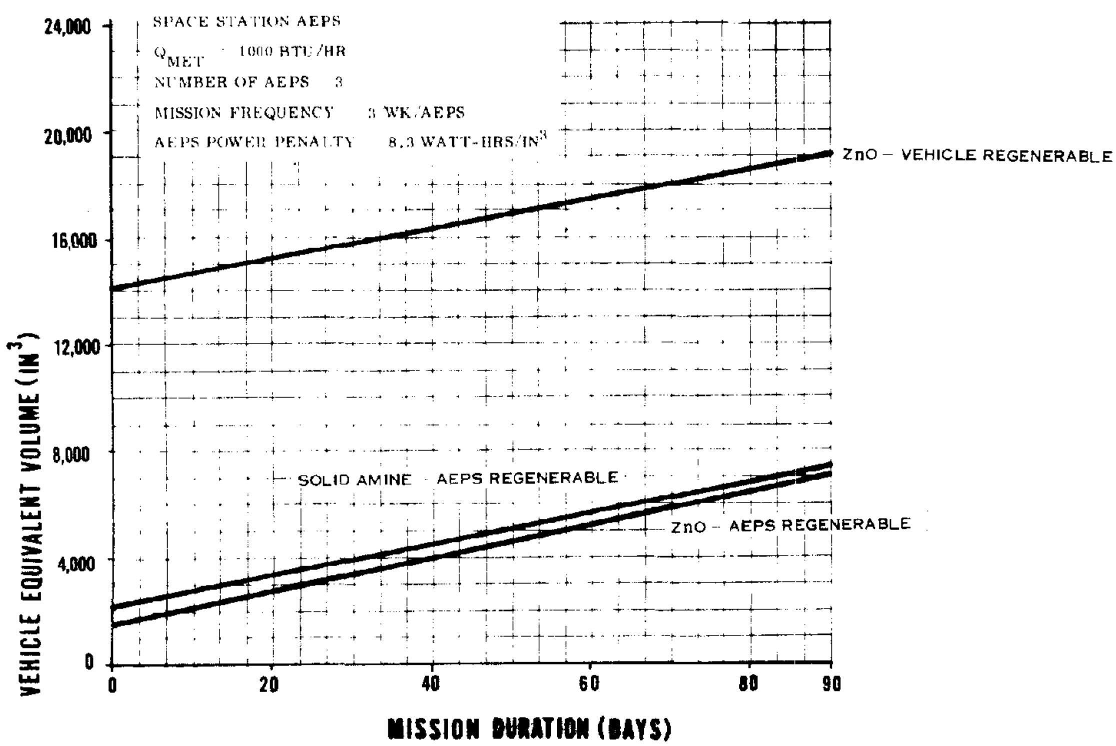


FIGURE 6–16

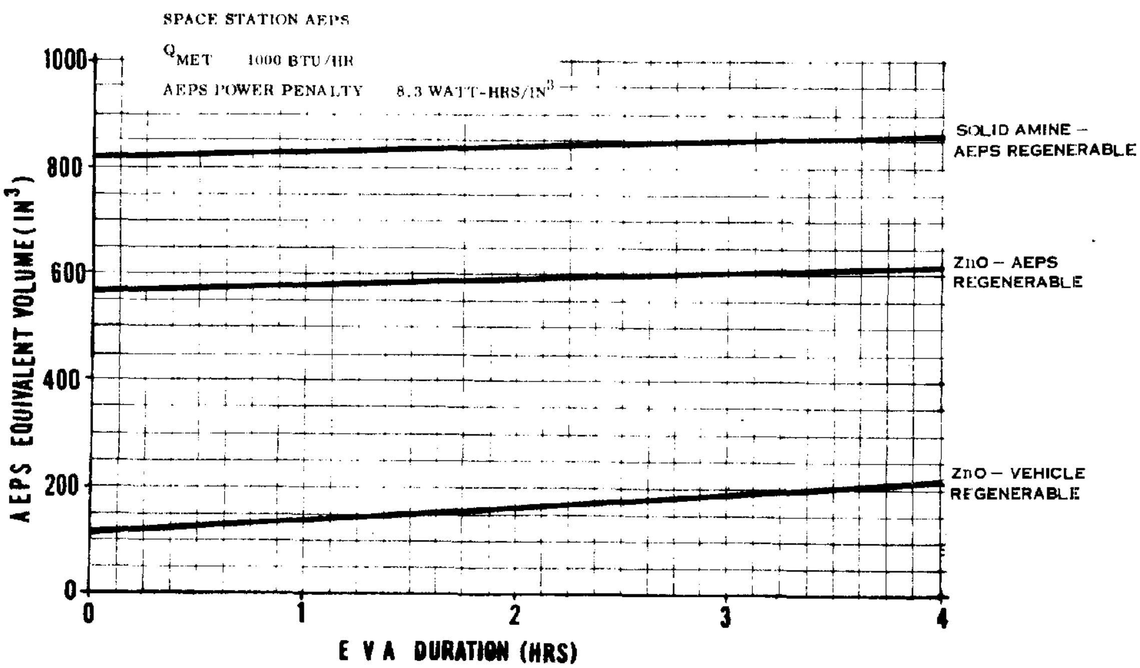


FIGURE 6–17

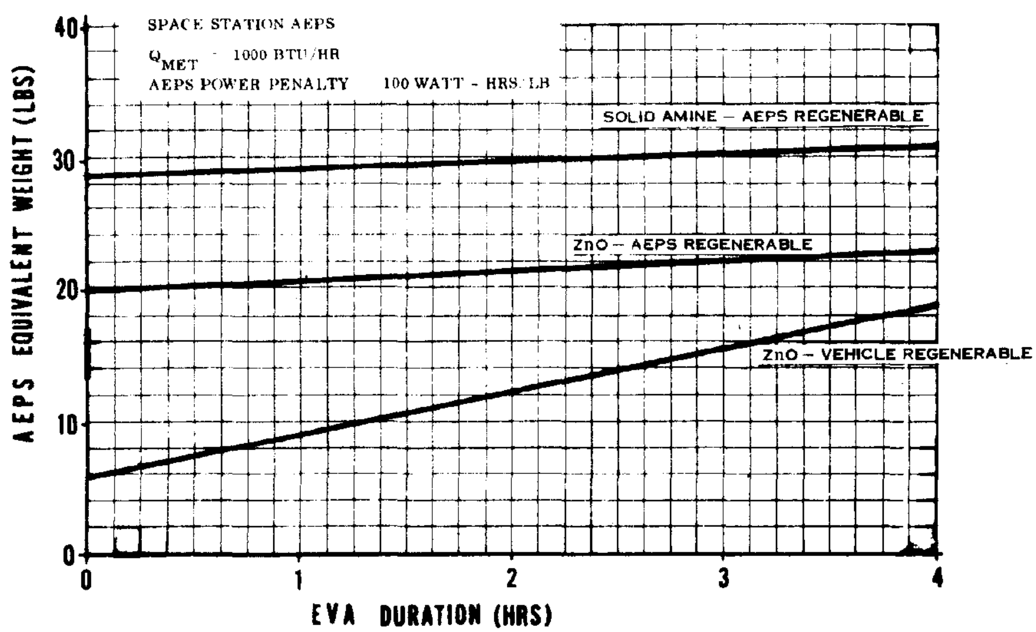
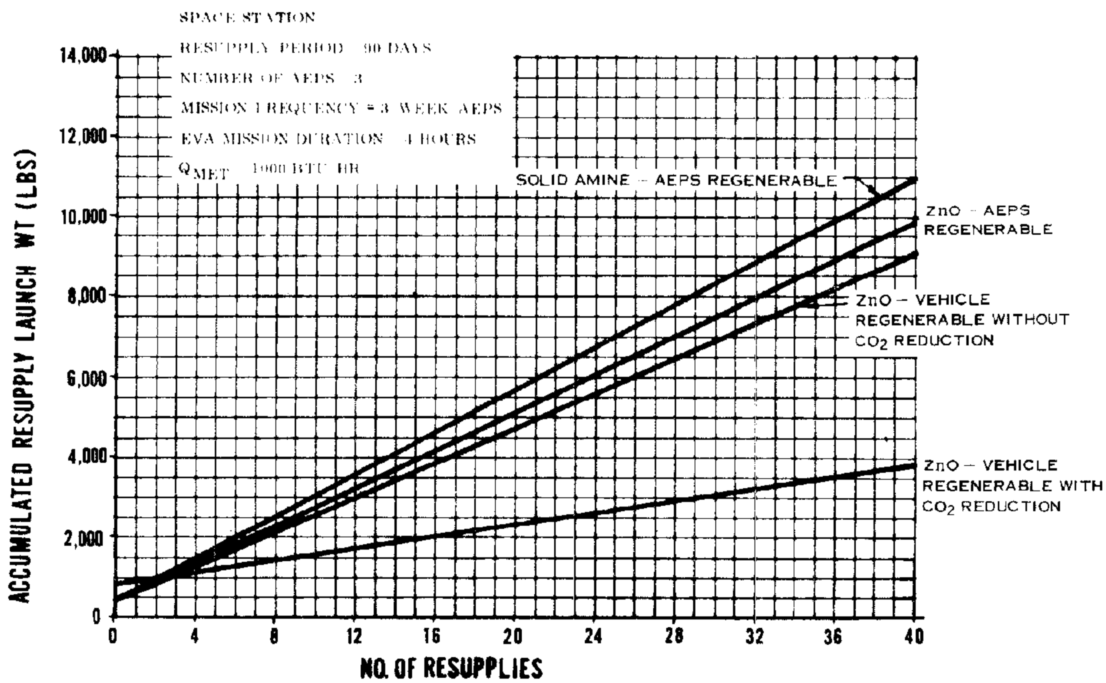


FIGURE 6–18



SPACE STATION
RESUPPLY PERIOD 90 DAYS
NUMBER OF AEPS 3
MISSION FREQUENCY = 3 WEEK AEPS
EVA MISSION DURATION 4 HOURS
Q_{MET} 1000 BTU HR
SOLID AMINE – AEPS REGENERABLE
ZnO – AEPS REGENERABLE
ZnO – VEHICLE REGENERABLE WITHOUT CO_2 REDUCTION
ZnO – VEHICLE REGENERABLE WITH CO_2 REDUCTION
ACCUMULATED RESUPPLY LAUNCH WT (LBS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
4
8
12
16
20
24
28
32
36
40
NO. OF RESUPPLIES

FIGURE 6–19

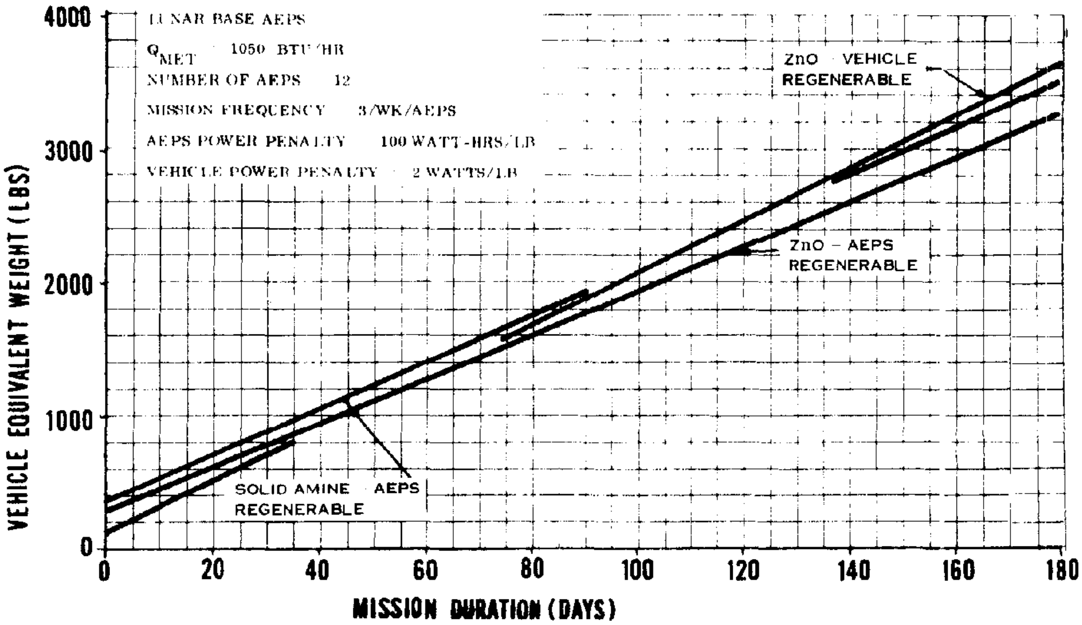


FIGURE 6–20

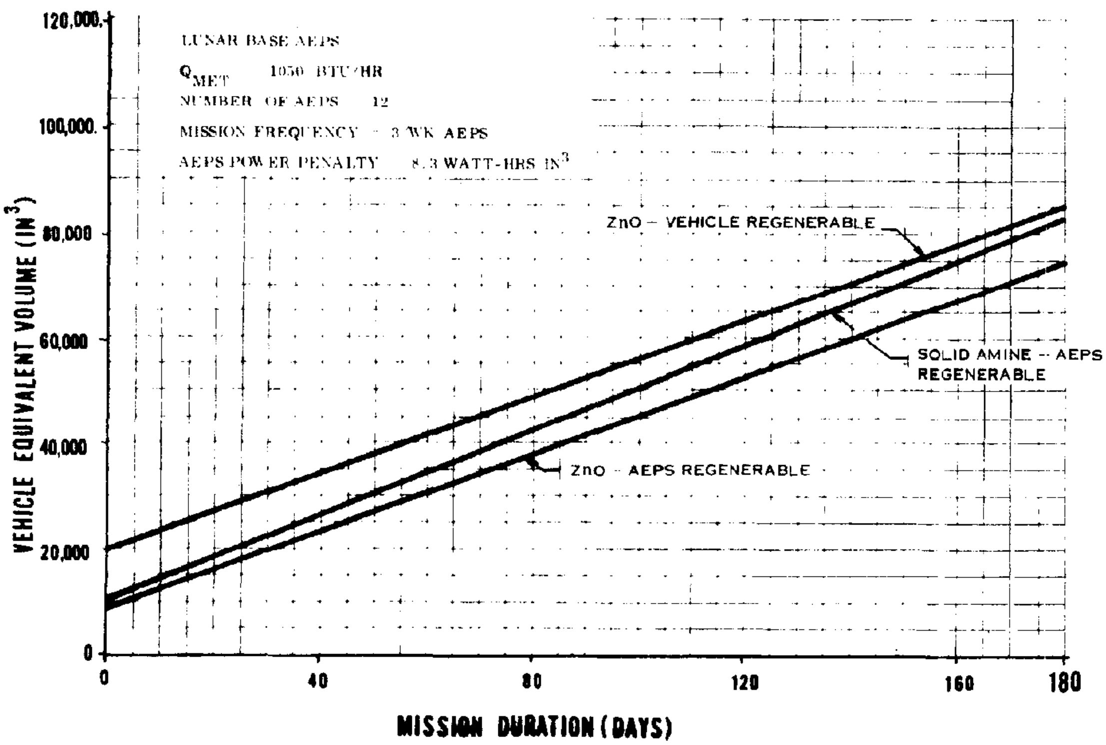


FIGURE 6–21

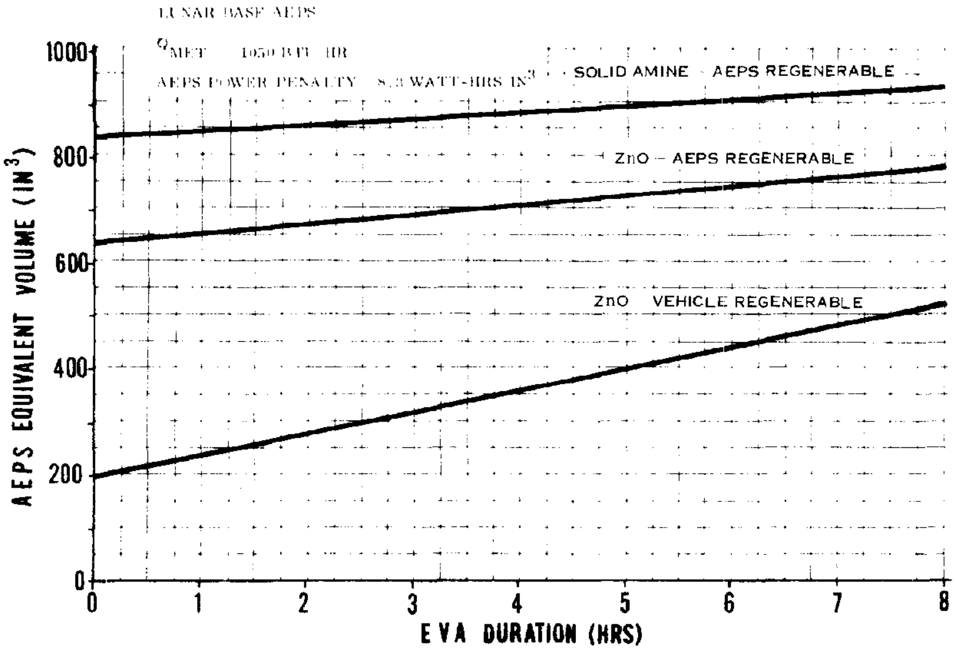


FIGURE 6–22

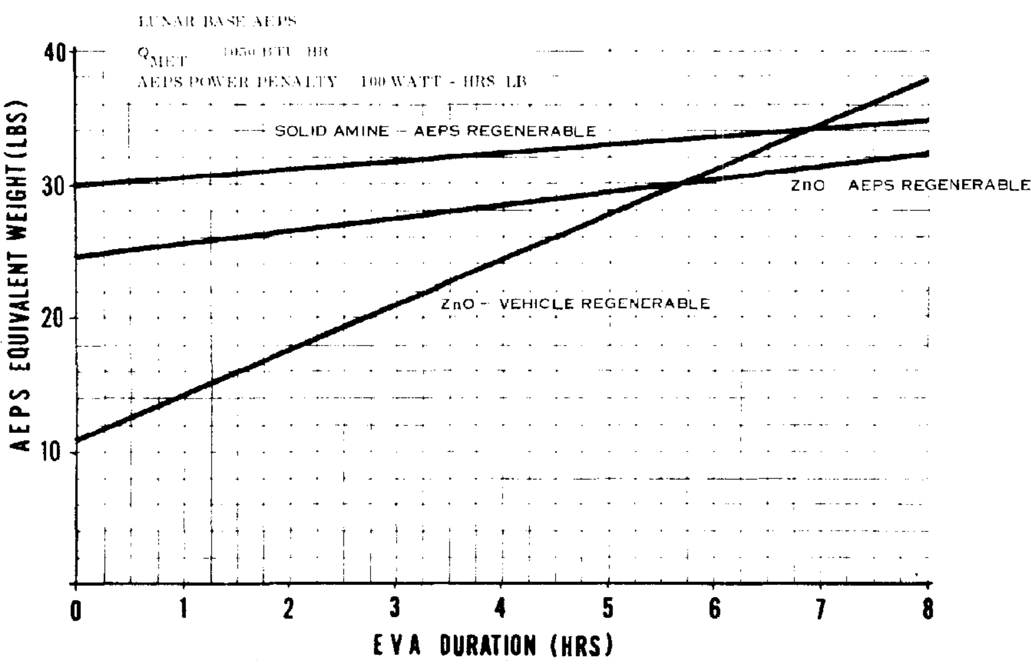


FIGURE 6–23

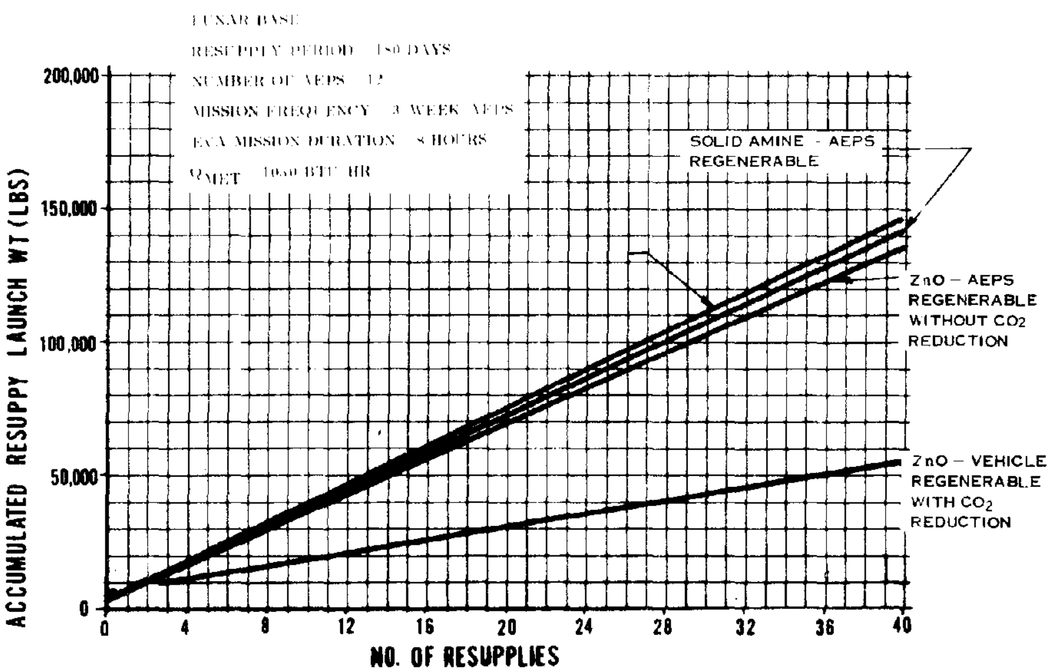

LUNAR BASE
RESUPPLY PERIOD 180 DAYS
NUMBER OF AEPS 12
MISSION FREQUENCY 3 WEEK AEPS
EVA MISSION DURATION 8 HOURS
Q_{MET} 1050 BTU HR
SOLID AMINE - AEPS REGENERABLE
ZnO – AEPS REGENERABLE WITHOUT CO_2 REDUCTION
ZnO – VEHICLE REGENERABLE WITH CO_2 REDUCTION
ACCUMULATED RESUPPY LAUNCH WT (LBS)
200,000
150,000
100,000
50,000
0
0
4
8
12
16
20
24
28
32
36
40
NO. OF RESUPPLIES

FIGURE 6–24

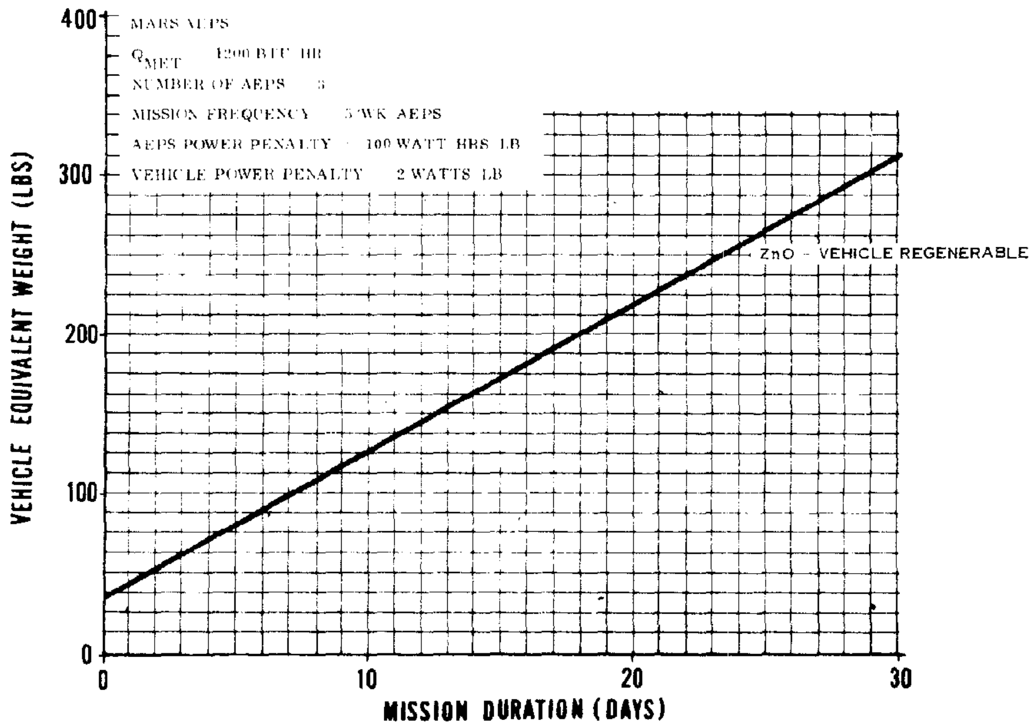


FIGURE 6–25

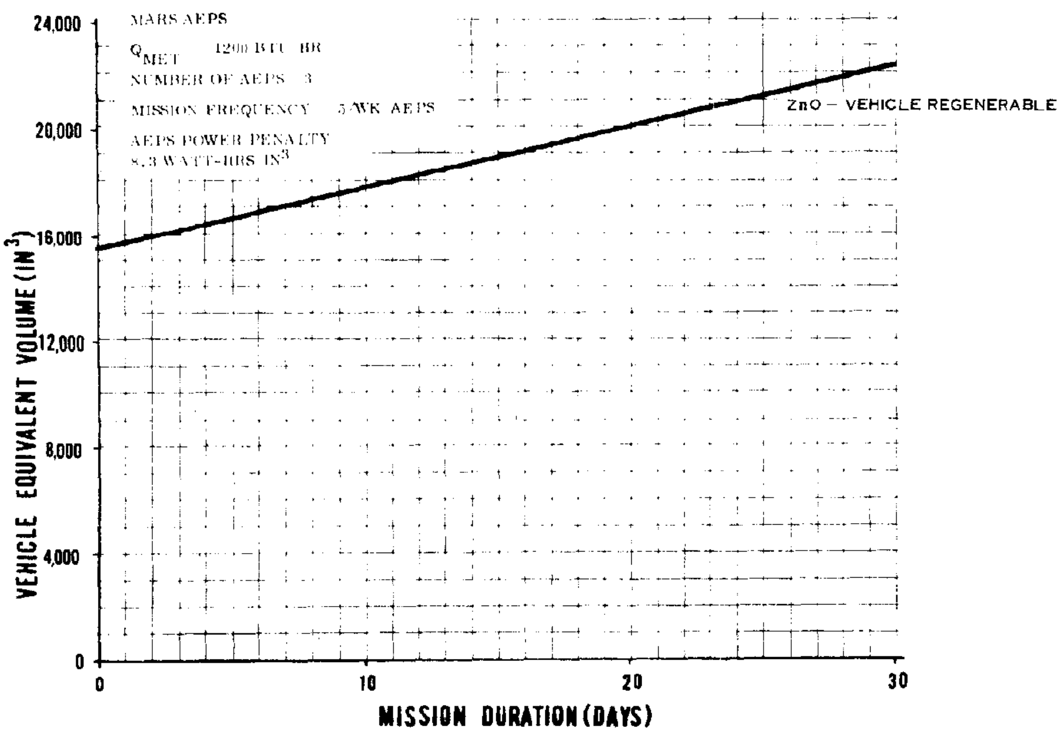


FIGURE 6–26

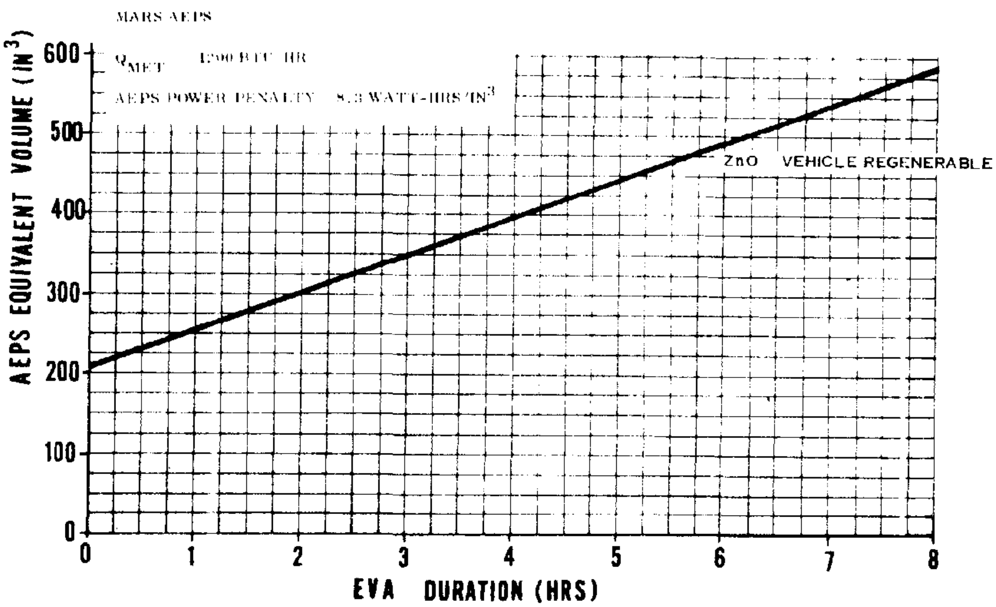


FIGURE 6–27

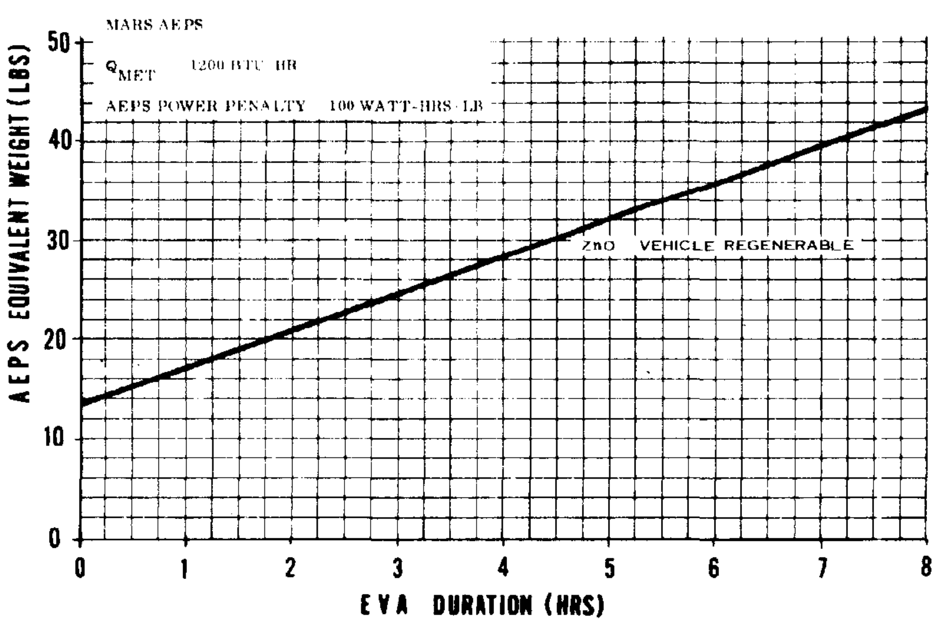


FIGURE 6–28

6.2 Phase Two Effort

6.2.1 Shuttle AEPS

6.2.1.1 Results & Recommendations

6.2.1.1.1 Thermal Control - Of the original nine (9) thermal control subsystem concepts carried into the go/no go evaluation, the following two (2) concepts successfully passed the go/no go, primary and secondary evaluations and were recommended to be carried into the system studies:

a. Water Boiler
b. Water Sublimator

6.2.1.1.2 CO_2 Control/O_2 Supply - Of the original seven (7) CO_2 control/O_2 supply subsystem concepts carried into the go/no go evaluation, the following six (6) concepts successfully passed the go/no go, primary and secondary evaluation and were recommended to be carried into the system studies:

a. LiOH
b. ZnO-AEPS Regenerable
c. ZnO-Vehicle Regenerable
d. MgO-AEPS Regenerable
e. MgO-Vehicle Regenerable
f. Solid Amine - AEPS Regenerable

6.2.2 Emergency Systems

6.2.2.1 Results & Recommendations

6.2.2.1.1 Thermal Control - Of the original eight (8) thermal control concepts carried into the go/no go evaluation, the following concepts successfully passed the go/no go and comparative evaluations and were recommended to be carried into the system studies:

Shuttle/Space Station

a. Water Boiler
b. Water Sublimator

Lunar Base/Mars

a. Water Boiler
b. Water Sublimator (except on Mars)
c. Expendable/Thermal Storage - PH_4Cl*
d. Expendable/Radiation - Heat Pump *

* Denotes a redundant primary system concept

6.2.2.1.2 CO_2 Control/O_2 Supply - Due to the overall system implications of some of the candidate CO_2 control/O_2 supply concepts (specifically the open loop and semi-open loop concepts), this evaluation was conducted on the system level.

7.0 AEPS OPERATING PRESSURE

7.0 AEPS Operating Pressure

7.1 General

Selection of a suit pressure level is dependent upon the physiological and operational constraints imposed on the crewman and his equipment by:

a. Denitrogenation requirements prior to decompression.

b. Oxygen toxicity.

The objective of this task is to establish an acceptable suit operating pressure level and an EVA mission pressure timeline for the use of a one-gas (pure oxygen) EVA Life Support System operating in conjunction with a two-gas (oxygen: nitrogen) Space Station, Lunar Base, Mars Excursion Module or Shuttle vehicle. To be considered acceptable, the selected pressure level should eliminate or require a minimum of prebreathing, yet not adversely affect the crewman or his performance. This section presents a discussion of decompression sickness and oxygen toxicity and their potential effect upon EVA.

7.2 Decompression Sickness

The problems associated with safe transporting from an area of high ambient pressure to an area of low ambient pressure have had a significant limiting impact upon the performance of caisson workers, divers, aviators and astronauts. The term used to define these problems is dysbarism. This includes 1) barotitis, 2) barosinusitis, 3) gastro-intestinal, 4) gas embolism, and 5) decompression sickness (bends).

The first three of these abnormalities are primarily caused by trapped gases which result from the evolution and expansion of dissolved gases. Any body cavity (paranasal sinuses, middle ear, periodontal abscesses, and intestines) unable to equilibrate with the ambient pressure during either a decompression or recompression could be a potential source of serious difficulty. The difficulties resulting from trapped gases can be minimized via such means as controlled diet; good health care, specifically ear, nose and throat; adequate venting of body cavities, specifically valsalva-manuevers or swallowing for middle ear relief; and passing flatus to ease abdominal discomfort. These conditions, however, are not considered of real significance with regards to a nominal or emergency EVA mission.

Gas embolism is not clinically synonymous with, nor a manifestation of decompression sickness. It refers specifically to gas embolization (i.e., blockage) of cerebral vessels subsequent to the rupture of lung tissue (parenchyma) by expanding gases. This gas formation should not be confused with the bubble formation that occurs in the circulatory system and/or tissues in decompression sickness. Gas embolization could, however, be expected to result in rare instances in healthy individuals from transient blockage of the respiratory pathways by general or localized gas trapping in the lungs, specifically in the alveoli as with atelectasis. Because acute atelectasis, as manifest in aviators through exposures to combinations of acceleration and high inspired PO_2, has been well documented, it is presented herein as a potential problem area to be evaluated in terms of the selected EVA mission profile.

Decompression sickness is the result of intravascular, intracellular and/or extra-cellular bubble formation. In general, bubbles of varying size tend to form in any tissue which has been saturated with an inert gas whenever the ambient atmospheric pressure is decreased to the point where the tissue pressure of the gas is approximately equal to twice that in the surrounding atmosphere. This results in a marked pressure gradient which drives the gas out of solution. This 2:1 ratio is a generalized parameter, proposed by early researchers, based primarily upon saturation diving experiences. It is based upon this theory, and later demonstrated, that the volume of N_2 which would be released during a controlled decompression would not vary significantly (from a pathological standpoint) until the total pressure was approximately halved. Much research has been accomplished in recent years, both in the development of Navy diving tables and altitude decompression curves, which indicates that this ratio was too conservative for the fast tissues (i.e., saturation/desaturation) and not conservative enough for the slower tissues. The most current values for this ratio, based upon empirical diving data and expressed in terms of half-times for representative tissue desaturation rates, are as follows:

Half-Time (Minutes)	Safe Ratio
5	5.5:1
10	4.5:1
20	2.45:1
40	1.75:1
75	1.75:1
120 to 240	1.94:1

At the present time, there is no universally accepted decompression ratio applicable to the aviation-aerospace environment. However, in the absence of such data, a conservative value of 1.75 to 1 is considered reasonable. Unlike oxygen and carbon dioxide, which are actively metabolized or transported, the rate of diffusion of the inert gas into the blood stream and thus into the expired air via the alveolar membrane, is far too slow to cope with the volume of inert gas evolved. Thus, the gas comes out of solution locally in the tissues to form bubbles. The number and size of the bubbles are proportional to the diffusion gradient existing between the partial pressure of the inert gas in the tissues and its comparable partial pressure at the lower ambient pressure. The greater the deviation from the pressure ratio gradient which has been proposed based upon considerable manned and animal test experience, the greater will be the number and size of the bubbles.

7.2 (Continued)

The inert gas which is most commonly proposed as a diluent for space vehicles is nitrogen, primarily because of the high gaseous nitrogen content in the normal sea level environment. It has an oil-water solubility ratio of approximately 5:1, which indicates a much greater solubility potential for fatty (adipose) tissues than for either muscular tissues or blood. The amount of nitrogen which can be expected to evolve out of solution depends upon the length of exposure to an environment containing nitrogen, the partial pressure of nitrogen in the environment, and certain composition factors of each individual. Obese individuals can be expected to dissolve considerably more nitrogen than a lean, well conditioned individual. During a decompression, nitrogen will evolve from all tissues of the body. However, to be eliminated in the expired gas, the nitrogen must be picked up and transported via the blood to the alveoli. If a large amount of nitrogen has been dissolved (such as if equilibration had occurred at sea level conditions), a watery "tissue" such as blood which is capable of holding only about 1/5 as much nitrogen as fat, would not be able to remove in solution the large amount of nitrogen at the rate at which it would evolve. Superimposed on this is the critical fact that adipose and boney tissues are poorly vascularized, thus compounding the perfusion (i.e., the quantity of blood to which the tissue is exposed) limitation in gas transport. Consequently, intravascular (capillary) and intracellular bubble formation occurs.

These are various factors which predispose an individual to decompression sickness and which definitely raise the need for screening processes in selecting candidate crewmen. Some of these factors are obesity, age, general physical condition, and CO_2 accumulation tendency. In general, older persons are more susceptible to decompression sickness than younger persons; this is apparently related to the status of the circulatory system. An increase in physical activity level results in a more rapid saturation of the tissues per unit of time than in a resting individual. This increased rate of tissue saturation is due to the increased rate of ventilation and circulation resulting in a more rapid transport of nitrogen to the tissues. An increase in CO_2 tension in the tissue appears to lower the threshold for bubble formation, which clearly points out the reasons why exercise is a detriment during decompression. Although the specific mechanism of this phenomenon is not clearly known, there is good reason to believe that it may be due to the high solubility and diffusibility of carbon dioxide as compared with nitrogen. There are other less well defined factors which also affect the susceptibility of man to decompression sickness, such as temperature, water balance, medication and/or drugs.

It is of particular interest to note that gross estimates of the incidence of decompression sickness symptoms in individuals following standard decompression profiles such as in Navy diving work and altitude chamber training flights place the occurrence as high as 4% in that specific population. Figure 7-1 presents the results compiled from a number of studies in which test subjects were exposed for two hours after prescribed prebreathing profiles to various simulated altitudes while at rest and while performing

7.2 (Continued)

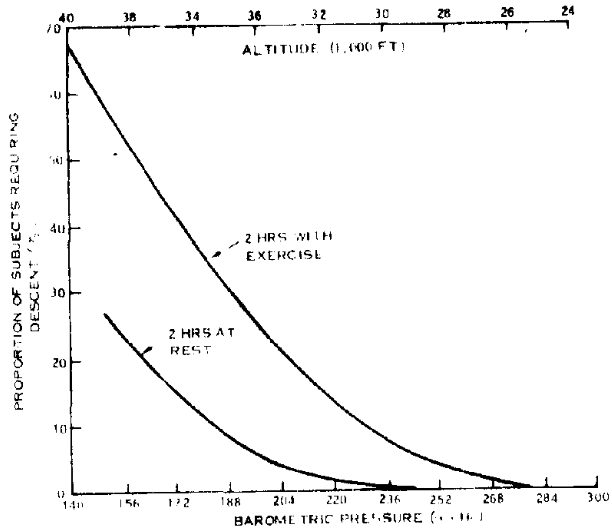


FIGURE 7–1. INCIDENCE OF INCAPACITATING DECOMPRESSION SICKNESS AT VARIOUS SIMULATED ALTITUDES.

moderate exercise. Unfortunately there is a lack of information regarding the incidence of decompression sickness when the duration of the exposure to the lower environmental pressures exceeds the 2 hours. The experimental results at the present time suggest that the incidence of severe decompression sickness at a given altitude increases progressively with time, particularly at the lower altitude.

For virtually all cases of decompression sickness, except perhaps neurocirculatory collapse which may require oxygenation and blood transfusions, the most practical and expeditious therapy is recompression.

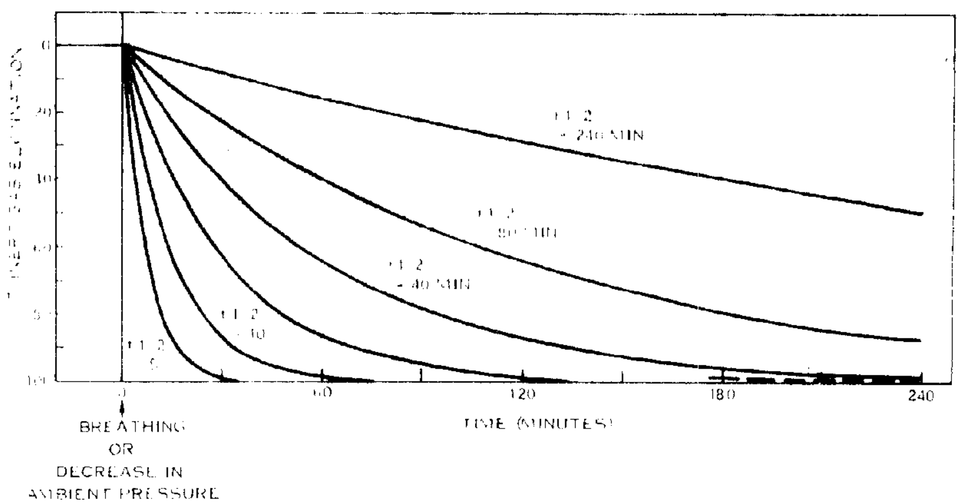
Protection from decompression sickness can be obtained by the controlled elimination of the inert gas (i.e., nitrogen) from the body. This can be accomplished in two ways: 1) staged or uniform decompression, which is a very time consuming procedure of allowing the body to wash out the nitrogen at a rate which is consistent with the capacity of both the lungs and the vascular system; and 2) accelerating this washout procedure by prebreathing oxygen at the initial equilibrated pressure for a specified period of time. Of the two choices, only prebreathing oxygen prior to decompression is feasible for any foreseen space mission.

The characteristics of inert gas exchange appear to be mainly determined by as well as limited by the quantity of blood perfusion (i.e., vascularization) through the various tissues of the body. In experiments conducted to determine the time constraints for whole body exchange of candidate inert gases (i.e., nitrogen, helium, xenon) a statistically significant similarity of constraints was noted. Thus to no discernible extent do the elimination values appear to be fixed by diffusion rate or by factors of permeability.

7.2 (Continued)

Additional evidence that the gas exchange rate constraints are determined by the blood tissue perfusion rates is that the circulation to the body tissues calculated from the gas-exchange rates closely approximates cardiac output, and the regional perfusion rates so calculated from gas-exchange are in agreement with existing measurement from other sources.

The amount of inert gas eliminated during numerous research efforts was also in close agreement with values calculated based upon solubility of the gas in body tissues and the uptake during saturation periods based upon known time constants for the test subject's gas exchange. Aside from the consideration of differential solubilities of the gases in blood tissue and fatty tissue, the prime limiting factor of gas exchange appears to be blood-tissue perfusion rate of body tissues. This implies that the diffusion rates of these dissolved gases are very rapid over such varied tissue and cell barriers as exists in the body as compared to the rate of movement of blood through the capillaries. In a consideration of inert-gas concentration in the tissues, it is necessary to have an understanding of the specifics of vascularization of the tissue, the proportion of arterial blood utilized/minute/tissue or organ, and an estimate of the average rate of inert gas removed/minute during various phased denitrogenations. The fraction of N_2 removed/minute, except for body fat, has been found to be the same as the blood-tissue perfusion factor. A factor of 0.3 means 30% removal of excess nitrogen/minute. Gas exchange rate closely approximates blood tissue perfusion rate, with of course the exception of body fat. Body fat has approximately the same vascularity as resting muscle, but the relatively high solubility of inert gases in fat, as compared with blood, causes the gas exchange rate for N_2 to be slower by a factor of 5 than the blood-tissue perfusion. Figure 7-2 presents a summary of an arbitrary



REFERENCE: BENNETT, P.B., ELLIOTT, D. H. ED. THE PHYSIOLOGY AND MEDICINE OF DIVING AND COMPRESSED AIR WORK. THE WILLIAMS & WILKINS COMPANY, BALTIMORE, 1969.

FIGURE 7–2. THE THEORETICAL TIME COURSE OF INERT GAS ELIMINATION FROM TISSUES

7.2 (Continued)

series of elimination rates for inert gas elimination from tissues. The various curves with specific half-time constants represent the elimination rates for different types of tissues found in the body. If the body tissues could theoretically be divided into six compartments based upon inert gas elimination rate with each compartment being formed of similar tissues, these curves delineate the problems to be faced in terms of time to safely decompress.

Figure 7-3 presents the results of a specific series of tests to determine the rates of elimination of nitrogen from various "tissue-compartments" in the body. It shows the actual whole body elimination profile (i.e., curved with plotted points) and estimations of the various parts-of-the-whole as indicated were present in Figure 6-2 for the

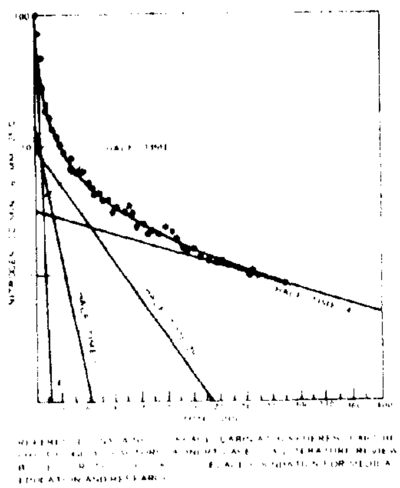
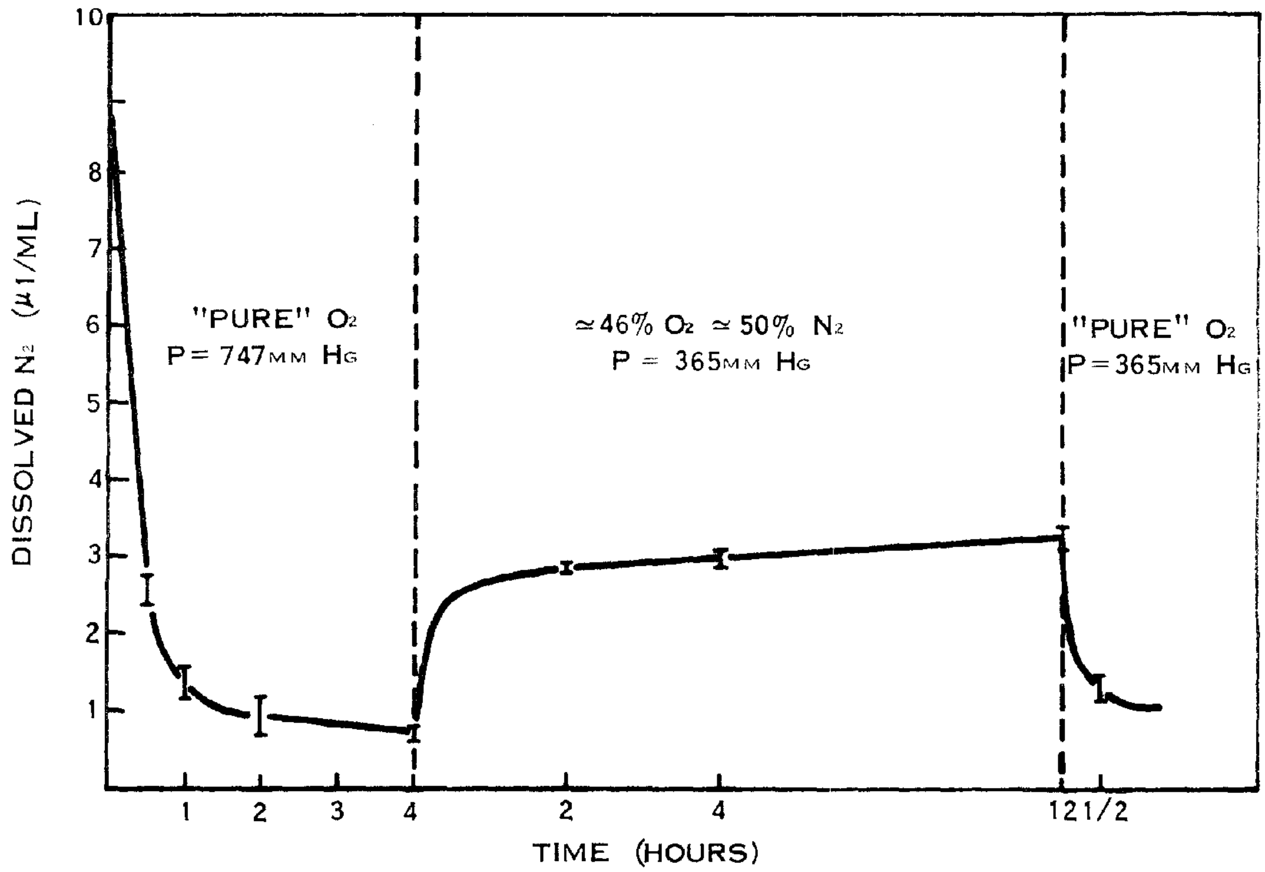


FIGURE 7–3. RATE OF NITROGEN ELIMINATION

discernible compartments. The half-time notations are presented to be consistent with the theorized 2:1 safe pressure reduction ratio previously discussed and are merely an indication of the minimum time to remove the critical quantity from the compartment to ensure a reasonably safe decompression. There are similar elimination rate curves for other inert gases, however, since N_2 is the diluent gas of primary concern, other curves are not considered.

Figure 7-4 presents the results of a significant test series which was conducted to establish an empirical relationship between the N_2 elimination rate of the whole body and the blood perfusion rate. This research effort isolated two specific elimination rates; the half-time of the fast component was estimated to be 12 minutes (i.e., 8.013μL of N_2 per mL of blood) and slow component nearly six hours (i.e., 1.164μL of N_2 per mL of blood). These constants appeared to hold true at both decompression conditions evaluated. It was also found that only after denitrogenation sufficient to reduce the dissolved N_2 in the blood to approximately 1 x 10^{-3} ml per ml of blood could any control of the bubble formation be affected. One of the most recent approaches to predicting required prebreathing times for safe decompressions resulted from the test efforts described above and is presented in Figure 7-5. This decompression profile



REFERENCE: DEGNER, E.A., IKELS, K.G., ALLEN, T. H. DISSOLVED NITROGEN AND BENDS IN OXYGEN—NITROGEN MIXTURE DURING EXERCISE AT DECREASED PRESSURES. AEROSPACE MEDICINE, 1965, 418—425.

FIGURE 7—4. ELIMINATION AND REACCUMULATION OF DISSOLVED N_2 IN VENOUS BLOOD OF MEN BREATHING DIFFERENT N_2 AND O_2 PARTIAL PRESSURES

exhibits close correlation with actual experience in both military and civilian aviation as well as limited aerospace flights and simulations. The application of this pre-breathing data, in light of the various physiological contributing factors mentioned above, and the limitation of the final space suit working pressure to an equivalent pressure altitude below the bends level (i.e., approximately 20,000 feet), should minimize the occurrence of decompression sickness during EVA operations.

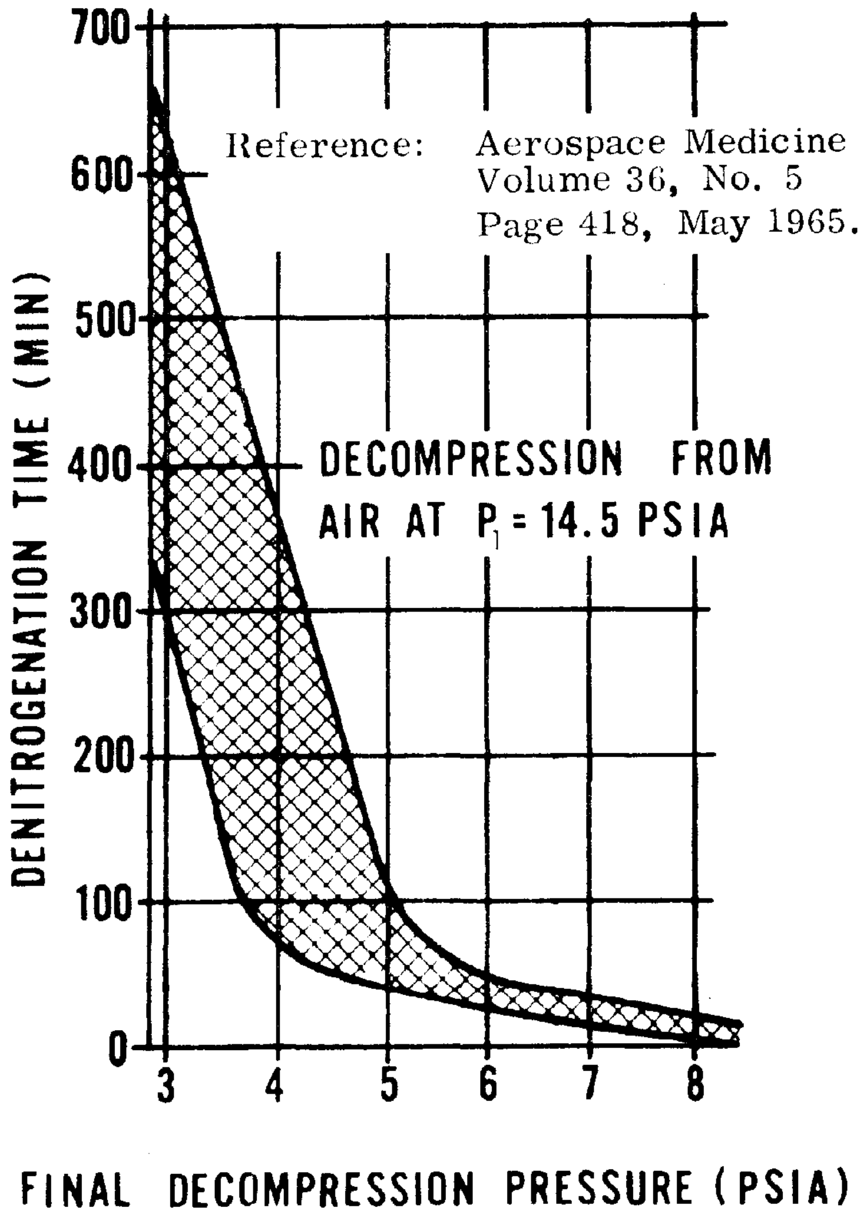
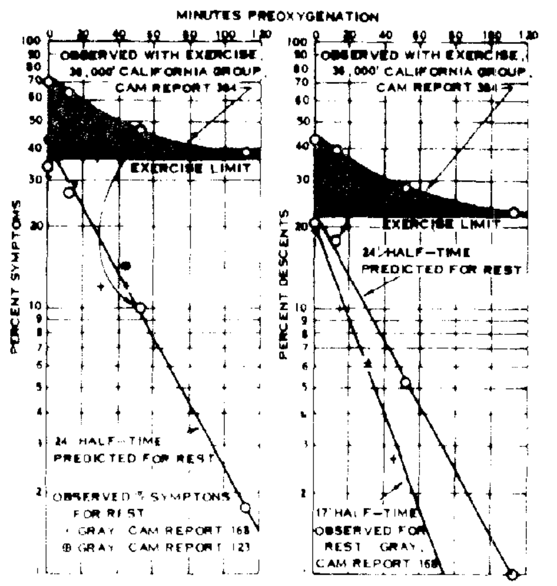


FIGURE 7–5. DENITROGENATION TIME REQUIRED PRIOR TO DECOMPRESSION

7.2 (Continued)

Another significant factor in the safe decompression of men is the associated activity or exercise level. There seems to be good correlation in the results of several studies presented graphically in Figure 7-6 involving decompression - denitrogenation-exercise profiles that a protection related limit exists beyond which no matter how much pre-oxygenation is applied, there will be no appreciable increase in protection. In every fractionation of the data available, no matter what the reduction/evaluation criteria was, (% symptoms or % abort), an exercise limit of approximately 49% protection was achieved.

It is most possible that this exercise limit effect has as its origin an increase in local concentration of CO_2 due to the excessive production of CO_2 during exercise and the limiting effects of high pressures of inspired O_2 on the CO_2 transport mechanism. It has also been theorized that CO_2 may be a significant contributor in terms of gas volumes to the degree of bends when it occurs.



REFERENCE: JONES, H.B. RESPIRATORY SYSTEM NITROGEN ELIMINATION MEDICAL PHYSICS VOL. II, YEARBOOK PUBLISHERS, 1950.

FIGURE 7–6. PREBREATHING PROTECTION LIMITS FOR DECOMPRESSION WITH EXERCISE

7.2 (Continued)

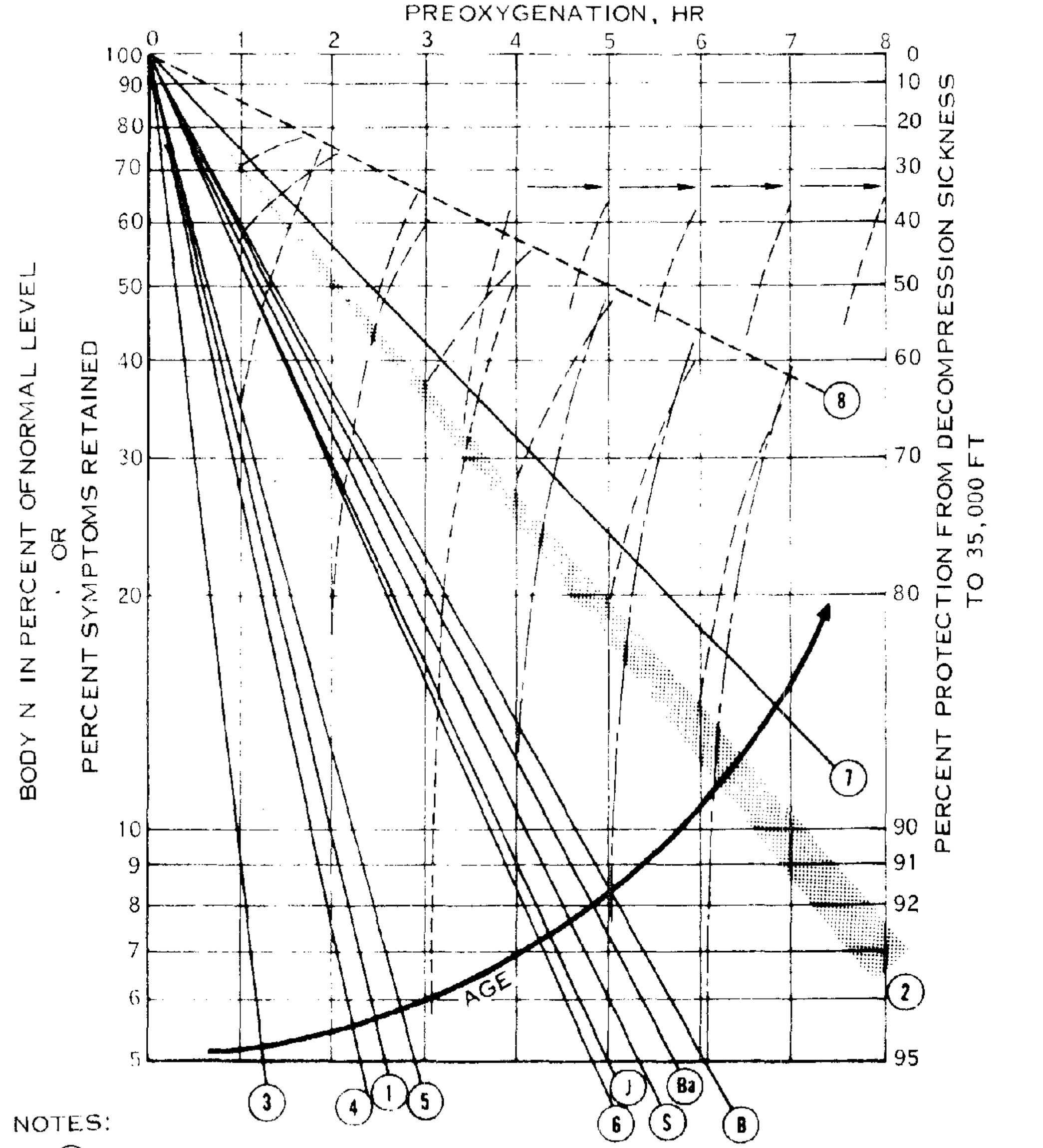
One of the most critical factors in applying decompression sickness protection criteria to future Shuttle, Space Station, Lunar Base and Mars missions is the frequency of exposures which are presently anticipated. There is very little quantitative data available to indicate the long term effects of or the potential hazards which may result from daily or routine decompression excursions where O_2 prebreathing is required. The present experiences of routine exposures of military/civiliam pilots and altitude chamber crews to decompression are not based upon any preestablished physiologically safe schedule, but are more a function of required work load. The treatment and allowable time before next exposure are established symptomatically; therefore, in terms of frequency of exposure, no preliminary constraints are available.

Figure 7-7 presents a graphical summary of all available applicable data from testing involving decompression sickness with prebreathing O_2 as a preventative means. The individual curves are taken from a number of unrelated studies which emphasized such varied effects as general physical condition, age, cardiovascular condition, weight, degree of bends proneness, experience or training with decompressions, etc. It is not presented herein for a point-by-point evaluation of each curve, but as an indication of the extremely wide limits within which non-military/non-test pilot type crewmembers for future space missions can be expected to fall. There is no best or even recommended, curve in this figure, as indicated by the included qualifying attachment, only specific population responses based upon personal variances.

The left ordinate in Figure 7-7 gives the body nitrogen as a percent of the physiological normal sea level value. The percent tissue nitrogen retained and the percent symptoms which are manifest are empirically synonymous. For example: Curves (1) and (2) represent the highest and lowest percent of residual nitrogen and associated percent bends protection found in the three specific tests which involved a population ranging in age from 17 to 24 years; curves (3) and (4) represent the fastest and average half-times in a single test of 18-year olds; curve (Ba) represents the average curve for slow individual protection rates from a specific test involving moderate exercise at simulated altitude (35,000 feet); and curves (5), (6), and (7) represent the data for the percentage of symptoms retained at 38,000 feet simulated altitude for 17-, 27- and 35-year olds, respectively.

As previously stated and as further delineated in Figure 7-7, there is considerable variation from person to person based upon a number of distinct physical, physiological and anthropometric factors. The stability of the probability of group performance is also striking and can be used to generate tables of the degree of protection afforded to any similar group by preoxygenation of any duration against specific altitude. Table 7-1 presents the minimum - probable protection rate for preoxygenated populations as compared with the same population without preoxygenation. The values in the table represent the percent increase in protection or percent decrease in symptoms to be

REFERENCE: NASA SP 117 SPACE CABIN ATMOSPHERE, PART III PHYSIOLOGICAL FACTORS OF INERT GASES. E.M. ROTH, M D, 1967



NOTES:

(B) BEHNKE

(S) STEVENS ET AL AVERAGE REPORTED N_2 ELIMINATION } GROUPS 24 YR

(J) JONES (1) FASTEST CURVE (2) SLOWEST CURVE

(4) AVERAGE CURVE (3) FASTEST CURVE, OF 18 YR OLD GROUP

(Ba) BATEMAN AVERAGE INDIVIDUAL PROTECTION RATE

(8) SLOWEST INDIVIDUAL PROTECTION RATE

CLARK ET AL (5) 17 YR (6) 27 YR, (7) 35 YR AGE GROUP

PERCENT SYMPTOMS RETAINED, 38,000 FT

BROKEN LINES INDICATE LOSS OF PROTECTION DURING 1 HR AIR BREATHING

FIGURE 7–7. COMPILATION OF TEST DATA AND EXPERIENCE RELATED TO RATES OF PROTECTION VS PREOXYGENATION TIME

TABLE 7-1
PROTECTION (A) OF GROUPS (B), COMPARED WITH DECOMPRESSIONS WITHOUT PREOXYGENATION

Preoxygenation (hours)	Minimum Protection (percent)	Probable Protection (percent)
0.5	16	26
1.0	29	45
1.5	41	59
2.0	50	70
2.5	58	77
3.0	61	83
3.5	70	87
4.0	75	91
4.5	79	--
5.0	82	--
5.5	85	--
6.0	86	--
6.5	89	--
7.0	91	--

(A) Zero protection equals incidence of decompression sickness of group without O_2 prebreathing, while ascending to altitude at 4,000 feet per minute.

(B) Group protection, not for individual protection.

(C) Reference: NASA SP-117 Space Cabin Atmospheres, Part III Physiological Factors of Inert Gases. E. M. Roth, M.D., 1967.

7.2 (Continued)

expected in a population as a result of prebreathing based upon the generalized data presented in Figure 6-7. An example of the use of this table is as follows: if at an altitude of 35,000 feet a group experiences 70 percent occurrence of symptoms and 50 percent forced decents with no preoxygenation, with one hour of prebreathing the comparable values would be 49.7% and 35.5%, respectively.

7.3 Oxygen Toxicity - Oxygen toxicity in man is a time-pressure dependent phenomenon, the two being inversely related. The tolerance of both man and animals to oxygen has been demonstrated to decrease exponentially with increasing pressure. Promptly upon beginning oxygen breathing and during the safe or symptom-free latent period of useful exposure before overt oxygen toxicity occurs, oxygen produces a number of physiologically important effects. These chiefly involve respiration, gas uptake, gas transport, hematological response, cell metabolism, and tissue gas exchange. Although apparently harmless during the latent period, they bear heavily on the rate of development of oxygen toxicity. The following paragraphs summarize and/or highlight the physiological basis of the more significant factors, based upon an extensive information search including personal contacts. Most of the data available in the literature pertaining to oxygen toxicity are based upon a few specific tests which were conducted under limited scope programs, where detailed analysis and data reduction was not accomplished, and follow-on testing to further delineate problem areas and resolve apparent inconsistencies in the baseline was never attempted. Much of the technical data is based upon animal experimentation, specifically the more current theories for the mechanisms of O_2 toxicity, methods of increasing the latent period, and prevention of overt symptoms. This data is in many respects both physiologically and statistically significant in its potential impact upon the problem of O_2 toxicity. However, it cannot be applied to man until considerable manned testing can be accomplished. Most of the manned testing reported in the literature and reviewed herein is of a qualitative nature in terms of the specific data points which result. Because of the potential hazards of exposing healthy men, even voluntarily, to high pressure oxygen environments and continuing the tests through the clinically critical overt symptom stages to define physiological responses and associated design criteria, very little truly applicable data is available.

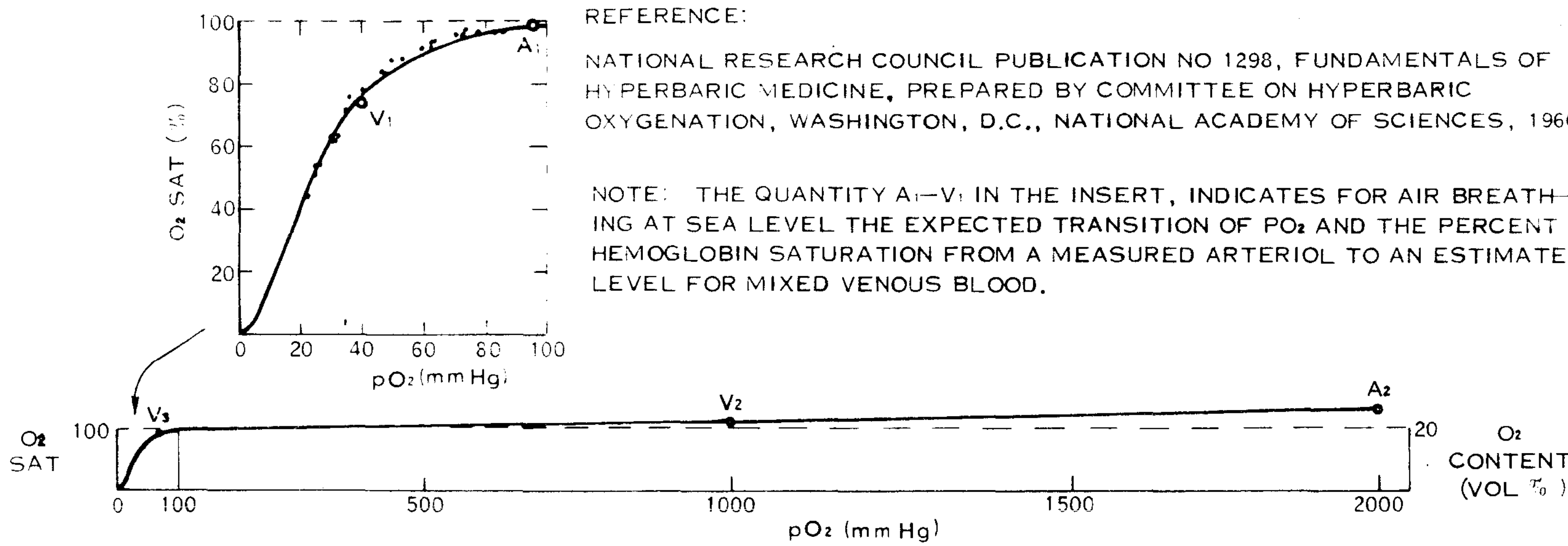
In normal respiring healthy individuals who have been breathing 100% oxygen long enough to eliminate most of the nitrogen from the lungs, the description of alveolar gas at sea level conditions can be expressed as follows:

PO_2	673 mm - Hg
PCO_2	40 mm - Hg
PH_2O	47 mm - Hg
P_{TOTAL}	760 mm - Hg

The washout of nitrogen from the alveolar gas of a normal lung occurs at an exponential rate and should be approximately 98% complete in about seven (7) minutes. Normally PCO_2 which is held close to 40 mm Hg by the regulatory processes of the respiratory control system, and PH_2O which depends only on body temperature, can be expected to remain very close to their sea level values, while the oxygen tension in the alveoli will rise almost millimeter for millimeter with the rise in pressure of the inspired oxygen. In the normal exchange of oxygen between the alveoli and blood, the PO_2 of the preliminary capillary blood comes to within a fraction of a millimeter of equilibrium with the oxygen tension of the alveolar gas. However, as alveolar PO_2 is increased a definite limitation of alveolar - pulmonary capillary oxygen transfer becomes evident. This difference can be reflected in an alveolar-arterial PO_2 difference as large as several hundred millimeters of mercury, specifically at 3 atmospheres of inspired oxygen. This limitation may well be due to the interference by high oxygen pressure with the normal combination of hemoglobin and carbon dioxide (CO_2), but it does not in itself explain the observed interference with transpulmonary oxygen uptake (i.e., the transport of O_2 from the alveolor to the arterial blood.)

Arterial hemoglobin saturation with oxygen is normally about 96 to 98 percent, even during air breathing in a sea level environment. Elevating the alveolar PO_2 leads to a further increase in the arterial oxyhemoglobin concentration until complete saturation is reached. While arterial oxygen tensions of many thousands of millimeters of mercury can be obtained by increasing the pressure of the inspired O_2, hemoglobin oxygenation is self-limited, and essentially complete saturation occurs at between 100 and 200 mm Hg. The physical solution of oxygen in the plasma of the arterial blood is not limited and as such increases indefinitely in proportion to the rise in inspired PO_2. Figure 7-8 shows the expected oxygen uptake curve of arterial blood as delineated by tests of normal men, at rest, with an inspired PO_2 of up to 3.5 atmospheres. In the area of the curve above the point at which complete saturation of the hemoglobin has occurred, the slope of the oxygen uptake line represents the physical solution of oxygen in the blood plasma as the inspired PO_2 continues to increase.

The solubility of oxygen in blood and plasma is affected primarily by body temperature. An increase in temperature will shift the O_2 dissociation curve to the right, resulting in less O_2 being held by the hemoglobin at any given PO_2. Normally this temperature effect is of some aid in the release of O_2 to the tissues, for the temperature is somewhat higher in the areas of actively metabolizing cells than near resting cells, resulting in a greater release of O_2. The solubility of oxygen in the plasma at an average



REFERENCE:

NATIONAL RESEARCH COUNCIL PUBLICATION NO 1298, FUNDAMENTALS OF HYPERBARIC MEDICINE, PREPARED BY COMMITTEE ON HYPERBARIC OXYGENATION, WASHINGTON, D.C., NATIONAL ACADEMY OF SCIENCES, 1966.

NOTE: THE QUANTITY A_1-V_1 IN THE INSERT, INDICATES FOR AIR BREATHING AT SEA LEVEL THE EXPECTED TRANSITION OF PO_2 AND THE PERCENT HEMOGLOBIN SATURATION FROM A MEASURED ARTERIOL TO AN ESTIMATED LEVEL FOR MIXED VENOUS BLOOD.

FIGURE 7–8. OXYGEN UPTAKE/LIBERATION CURVE FOR NORMAL MEN AT REST, RESPIRING 100% O_2 AT VARIOUS AMBIENT PRESSURES body temperature of 37C ± 0.5C is approximately 0.0214 ml O_2/ml plasma/atmosphere of pressure. Because the solubility of oxygen is also greater in a given volume of red blood cells (RBC) than in the same volume of plasma, it is necessary to take into account the hematocrit (i.e., hemoglobin concentration or oxygen capacity) when estimating the physical solubility of oxygen in the whole blood. Under normal conditions, the solubility of oxygen in whole blood is approximately 0.0236 ml O_2/ml blood/atmosphere of pressure. This means that for an increase of 760 mm Hg in the arterial oxygen pressure, approximately 2.4 ml of oxygen will dissolve in each 100 ml of arterial blood. Thus the solubility of oxygen in whole blood, as affected by both body temperature and blood cell volume, must be taken into account in estimating delivery of oxygen to the tissues and assessing the resulting O_2 toxicity potential. In the normal air breathing state, almost all of the oxygen supplied to tissue cells is derived from oxyhemoglobin in capillaries. However, when oxygen is breathed at such a high partial pressure that it is supplied from physical solution, the oxyhemoglobin passes unchanged through the capillaries and serves no chemical function in oxygen transport. As hemoglobin fails to release oxygen, this also affects the transport of CO_2 from the tissues. Fully oxygenated hemoglobin is less effective than reduced hemoglobin as a buffer for hydrogen ions. It is on this basis that an increase in arterial PO_2 above normal leads to a rise in tissue PCO_2 and acidity. An important consideration in exposure to high PO_2 is the degree to which CO_2 will accumulate in the tissues. In the normal air breathing state, the deoxygenation of hemoglobin makes available enough basic groups to transport the entire amount of CO_2 produced by a tissue with an average respiratory quotient of 0.7, and to do so without change in ph.

There is considerable evidence, based upon both manned and animal tests as well as isolated incidences on Apollo flights, that discrete hemotalogical changes directly related to the inspiration of oxygen at higher than normal pressures and/or the absence of a diluent in the inspired gas have occurred. Specifically, changes in RBC mass and the O_2 transporting capacity of the blood have been observed on Gemini and Apollo missions; destruction of RBC's (i.e., mild hemolysis), changes in white blood cell (WBC) mass and other formed elements in the blood have been observed as subtle trends or preflight and post-flight changes. However, the significance of these changes should not be overlooked. It is acknowledged that the changes, specifically red blood cell mass, may be the result of normal body compensatory mechanisms and that the parameteric degradation is self-limiting, within safe limits. There is, however, no empirical data available with which to evaluate the problem. It is impossible at the present time to assess the potential impact of these problems upon an EVA mission profile involving intermittent exposures.

The harmful effects of oxygen on the lung membranes and lung functions are due both to chemical actions related to the increase in inspired PO_2 and to the physical consequences of excluding the inert carrier gas from the pulmonary passages. As with any tissue, the primary cause of O_2 toxicity is the action of oxygen on the cellular metabolic processes. The rate of development and the degree of chemical damage to the respiratory passages and the conjunctivae is porportional both to the PO_2 and to the duration of the exposure. The term "irritation" often used to describe associated symptoms is a misnomer in that the effect is undoubtedly a distinct form of biochemical toxicity involving the cells of all exposed mucosal or serous surfaces. The effects upon the respiratory tract appear not only to have a threshold dose, but also to begin only after a definite latent period. Although the concept of a safe latent period is considered valid, even on theoretical grounds, it should also be remembered that truly objective means of determining the presence and degree of pulmonary or epithelial irritation are not adequate for assessing pulmonary oxygen toxicity until it has become subjectively prominent (i.e.; as a symptom). Figure 7-9 shows most of the available and applicable information concerning pulmonary oxygen tolerance in man. In the results of studies related to the evolving program for manned spaceflight, testing involving pure O_2 at a reduced ambient pressure of approximately 250 mm Hg has been breathed by normal, healthy men for up to 30 days without chemical or other overt pulmonary changes. However, pulmonary, nasopharynegel, and conjunctional irritations have been clearly observed in men exposed to pure oxygen at sea level pressures (760 mm Hg) for 24 hours. Exposures for longer periods at the same O_2 pressures has led to severe bronchopneumonia.

It should be noted that breathing 100% O_2 produces no overt biochemical toxicity when the ambient pressure is maintained low enough so that the alveolar PO_2 is not greater than normal sea level value. This situation routinely exists in aviation and in an oxygen filled altitude chamber or spacecraft where the total pressure is approximately 187 mm Hg ($P_t = PO2$). Although chemical oxygen toxicity under these circumstances is clinically inconceivable, it has been demonstrated that random blockage of bronchioles, even by normal secretions, can lead to diffuse, progressive, and eventually severe pulmonary atelectasis due to rapid and complete absorption of the gaseous water, carbon dioxide and oxygen from obstructed alveoli. Pulmonary atelectasis is a very real potential physical complication of oxygen breathing when the inspired PO_2 is high enough or the exposure long enough to produce a chemical pulmonary irritation, or in the event other factors such as infection interferes with the patences of the terminal pulmonary passages.

Based upon the published reports of several investigators, an index of eminent overt O_2 toxicity in man has been prepared which relates changes in the vital capacity of the individuals versus the pressure of inspired O_2 and the duration of the exposure. The tests summarized in Figure 7-10 involved many exposures of normal human subjects to higher than normal O_2 pressures, and compared the degrees of pulmonary hazard (i.e., changes in vital capacity) with the risk of central nervous system (CNS) injury as the duration of continuous exposure to pure O_2 was increased to various pressures which are directly related to treatment of bends. The CNS data is related to data summarized in Figure 7-9. It should be noted that although these curves delineate

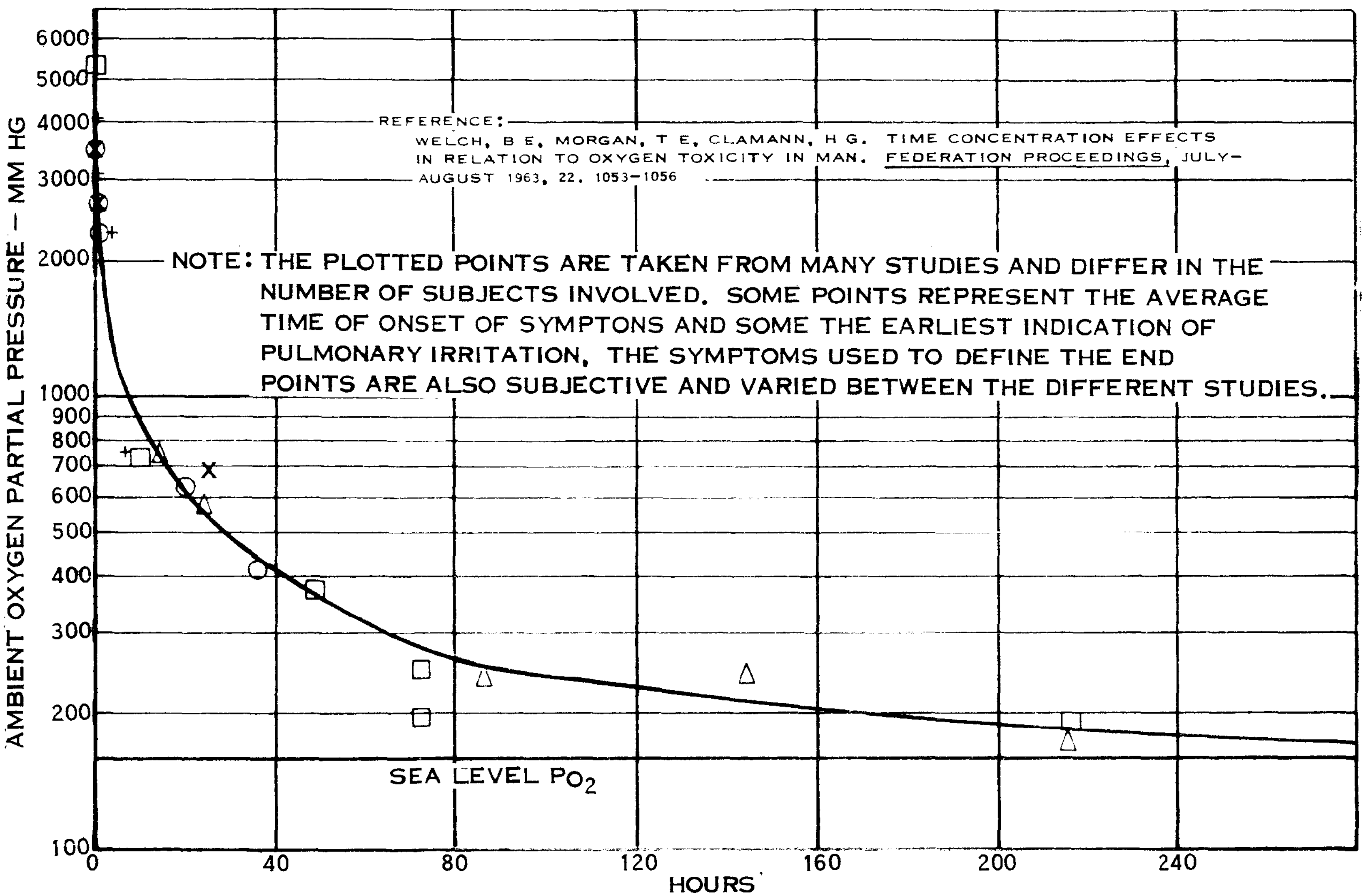


FIGURE 7–9. AVERAGE TIME OF ONSET OF OVERT OXYGEN TOXICITY SYMPTOMS AS A DIRECT FUNCTION OF O_2 PARTIAL PRESSURE

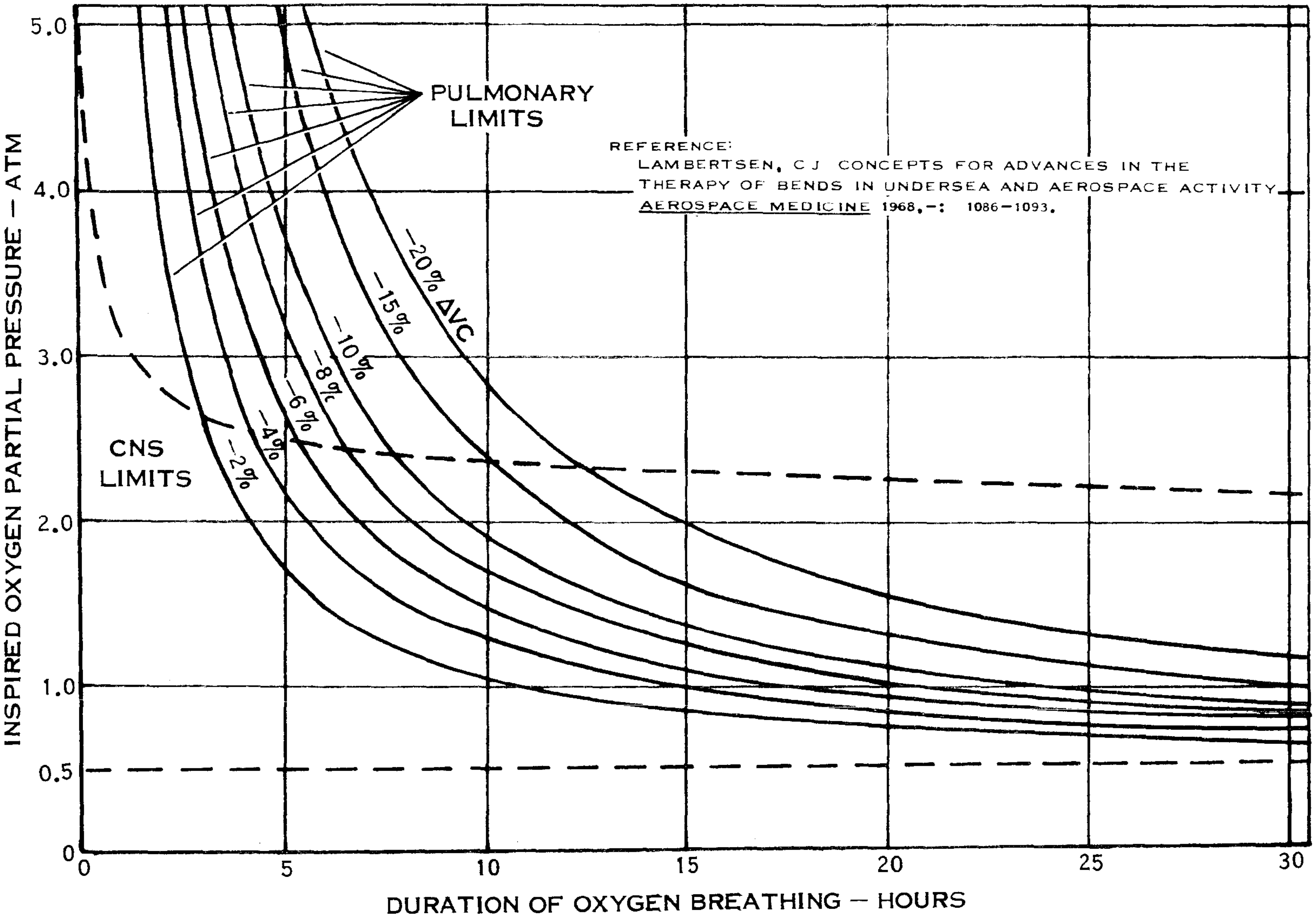


FIGURE 7—10. PULMONARY OXYGEN TOLERANCE CURVES IN NORMAL MEN BASED UPON CHANGES IN 50 PERCENT OF THE PARTICIPATING SUBJECTS

an apparent quantitative physiological effect, the level of acceptable decrease in vital capacity cannot be presently established and the effects or impact of intermittent exposures as opposed to continuous exposures, as accomplished in these studies, cannot be implied or assessed.

An overt symptom of CNS oxygen toxicity is a generalized convulsion, which in man resembles the seizure of an epileptic. The convulsion is usually preceeded by the occurrence of localized muscular twitching, especially about the eyes, mouth, and forehead. Small muscles of the hands may also be involved and a definite incoordination of diaphragm activity in respiration may be noted. Once they begin, these symptoms increase in severity over a period that may vary from a few minutes to nearly an hour dependent upon PO_2, duration of exposure, activity level, etc. The convulsions of O_2 toxicity occur only after a "safe latent period" where length is inversely proportional to the pressure of inspired oxygen. Considering the many factors that can affect not only the dose of oxygen at the cellular level, but also the chemical action of oxygen on intra-cellular enzymes, it is not unusual that the latent period for the development of gross convulsions varies greatly from person to person and even within one person. The rate of development of oxygen convulsions is also increased by exercise, a factor of significant importance in aerospace applications. The physiological basis of this influence has not been established. At least one of the possible factors for explaining this relationship has been present in every study of O_2 tolerance in exercise, but none in all; it is therefore not understood whether the neurophysiological effects of muscular activity or an increased brain PO_2 due to some interference with CO_2 elimination is responsible for the shortened latent period for oxygen toxicity, specifically convulsions in exercise. If the conditions of pressure and duration of a single oxygen exposure does not result in overt, acute manifestations of central nervous system or pulmonary toxicity, it is unlikely that clinically significant residual harmful effects will be produced. This fact is well demonstrated by the extensive and apparently successful use of self-contained oxygen rebreathing apparatus by the military, with daily exposures to high oxygen tension repeated for several months.

Complete prevention of the direct, intracellular, enzymatic phenomena of oxygen toxicity is not presently possible; in fact, based upon the expressed opinion of principle researchers in related fields, it is very unlikely that it will ever become possible to successfully inhibit or prevent cellular oxygen toxicity from occurring in the presence of high cellular oxygen tension. At present the most practical approach is to avoid excessive pressure and the duration of exposure to oxygen.

One of the most promising and in fact practical experimental method being proposed for extending man's ability to use high O_2 pressures is the use of a carefully controlled schedule of alternations of exposure to high and normal levels of PO_2. Such purposeful, brief interruptions of exposure to high inspired $O2$ pressures has markedly extended

7.3 (Continued)

the oxygen tolerance or latent period in experimental animals, and indicates that their rate of recovery from the direct toxic actions of oxygen is considerably greater than the rate of development of overt oxygen toxicity. The alternation of low and high inspired PO_2 offers a practical approach to increasing the duration of the total exposure to a particular high O_2 pressure within a given time period. Unfortunately, no systematic extension of this principle to man has been attempted. For its full exploitation in programs like the Shuttle program, the optimal relationships between the duration of exposure to high PO_2 and the length of the interruption of the exposure must be determined for various levels of inspired PO_2. In addition it must be recognized that the relationships of rate of development of toxicity and of recovery from it will undoubtedly be different for the pulmonary, central-nervous system (CNS) and other forms of O_2 toxicity.

7.4 Effect on EVA

The present Apollo A-7L-B suit operates at 4.0 psia maximum and would require from 3 to 4 hours of oxygen prebreathing if utilized for any future planned EVA missions. This prebreathing requirement is costly both in time and supporting equipment. If suit pressure is increased to approximately 8 to 14.7 psia, the following advantages occur:

a. No prebreathing required.

b. No O_2 purge required for transfer from cabin to EVA equipment.

c. Other crewman may remain in cabin until needed for EVA emergency or rescue.

The disadvantages associated with a higher pressure suit are:

a. Slight weight increase

b. Some advanced technology required

Ideally, the optimum suit pressure level is that level which eliminates prebreathing, does not adversely affect the crewman or his performance, and has a minimum impact on the mission vehicle. However, to eliminate prebreathing requirements we must elevate the operating pressure level of the suit to a level (approximately 8 psia) that may or may not adversely affect the crewman due to O_2 toxicity. Therefore, before suit pressure level can be selected, the physiological impact of the following factors must be determined:

7.4 (Continued)

a. Required versus tolerable O_2 prebreathing time.

b. O_2 partial pressure exposure limitations including frequency and duration.

c. Safe decompression/recompression levels, rates and frequency.

However, for routine exposures over an extended period of time, it appears there is insufficient data available to establish a physiologically safe profile from either a decompression sickness or an oxygen toxicity standpoint. Too little is known about the cumulative effects of frequent exposures to oxygen tension greater than normal sea level values, and even less is known about the effects of frequent exposures to decompression/recompression cycles. Just the daily decompression of crewmen based upon experience with altitude chamber crews may be excessive because of the fatigue resulting from the procedure, compounded by the physical exertion of the planned EVA.

The additive effects of these stresses have never been assessed theoretically or empirically. Therefore, it appears that without a comprehensive test program specifically oriented to the application in question (either Space Station, Lunar Base, Mars or Shuttle), establishment of an acceptable and safe physiological baseline is not possible.

.5 Summary

For the purposes of the remainder of the AEPS system studies effort, the following EVA mission baseline requirements are recommended for use with a one-gas (pure oxygen) AEPS in conjunction with a two-gas (oxygen nitrogen) Space Station, Lunar Base, Mars Excursion Module (MEM) or Shuttle:

a. Space Station - Lunar Base - MEM - Shuttle Atmosphere

- P_T = 10.0 - 14.7 psia
- P_{O_2} = 3.3 psia
- Diluent = Nitrogen

b. Minimum pre-breathing period at total base pressure (10.0-14.7 psia), 100% O_2 is 43 minutes.

c. Decompression rate shall not exceed 1.0 psi per second.

d. AEPS working pressure is 6.75 psia with a maximum exposure time of 8 hours.

7.5 (Continued)

e. Recompression rate shall not exceed 0.10 psi per second.

f. Minimum off-duty time for crewmen returning from an 8 hour EVA is 24 hours.

The recommended crewman pressure timelines for a Space Station/Shuttle EVA and for a Lunar Base/Mars EVA are presented in Figures 7-11 and 7-12, respectively.

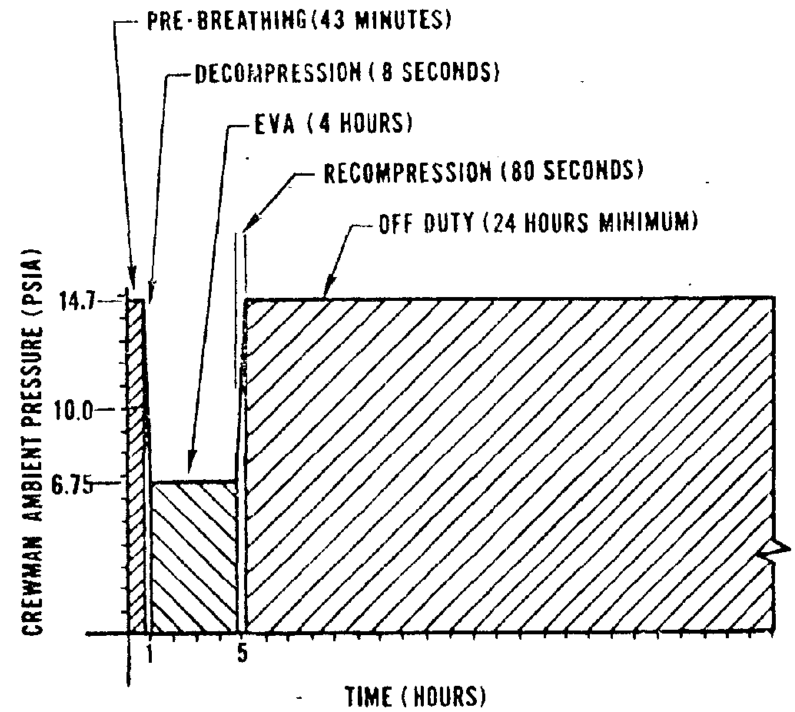


FIGURE 7–11. SPACE STATION/SHUTTLE EVA CREWMAN PRESSURE TIMELINE

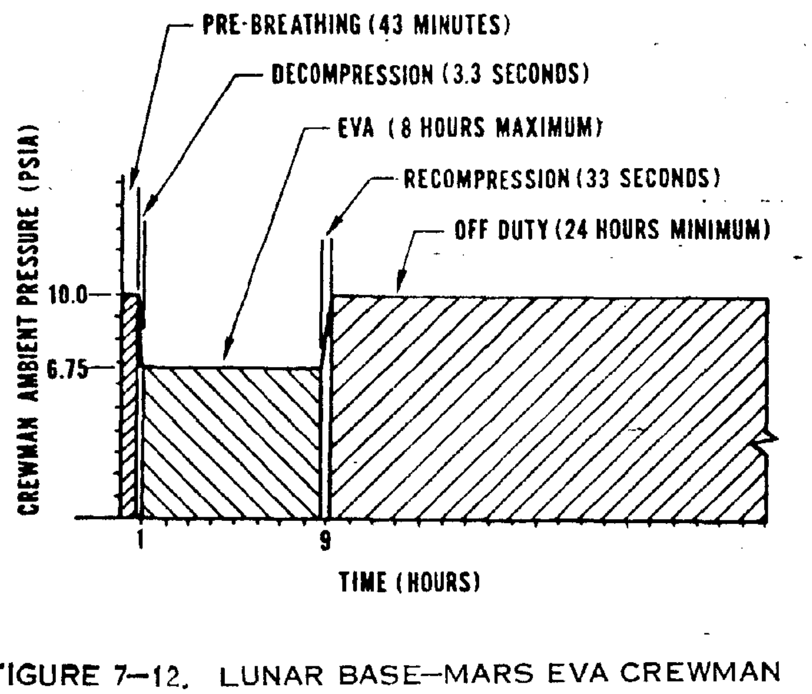


FIGURE 7–12. LUNAR BASE–MARS EVA CREWMAN PRESSURE TIMELINE

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